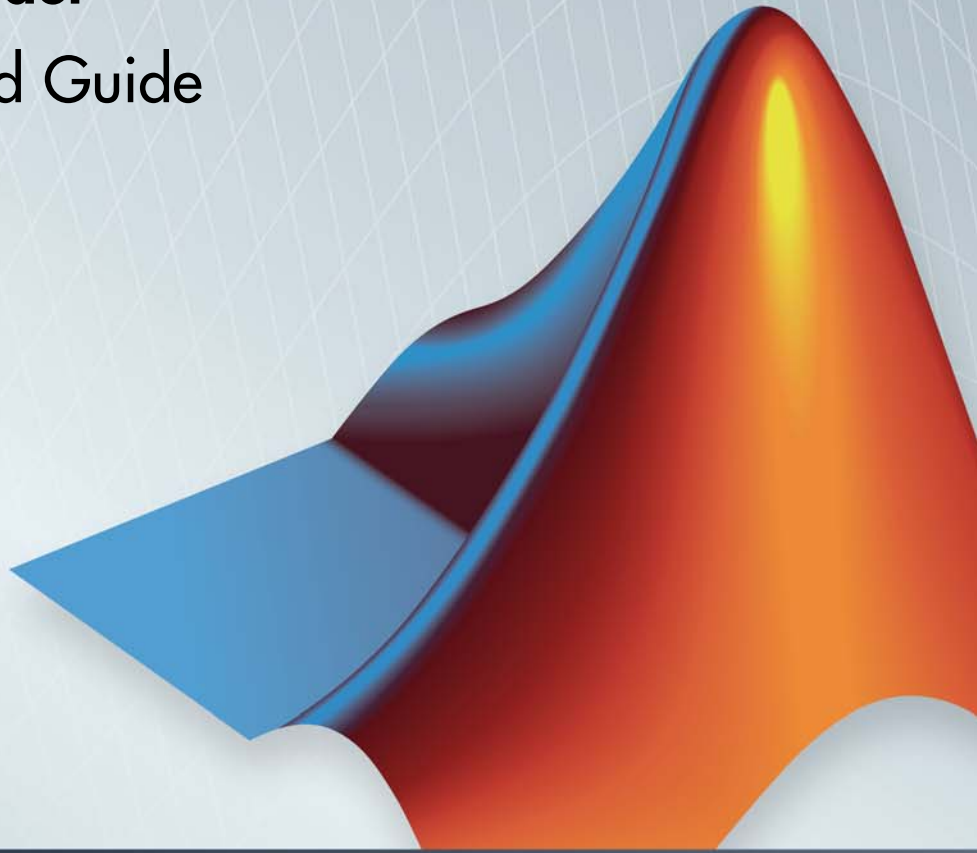


# Embedded Coder®

## Getting Started Guide

**R2013a**



**MATLAB® & SIMULINK®**



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For contact information about worldwide offices, see the MathWorks Web site.

*Embedded Coder<sup>®</sup> Getting Started Guide*

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### Revision History

April 2011	Online only	New for Version 6.0 (Release 2011a)
September 2011	Online only	New for Version 6.1 (Release 2011b)
March 2012	Online only	New for Version 6.2 (Release 2012a)
September 2012	Online only	New for Version 6.3 (Release 2012b)
March 2013	Online only	New for Version 6.4 (Release 2013a)

## **Check Bug Reports for Issues and Fixes**

Software is inherently complex and is not free of errors. The output of a code generator might contain bugs, some of which are not detected by a compiler. MathWorks reports critical known bugs brought to its attention on its Bug Report system at [www.mathworks.com/support/bugreports/](http://www.mathworks.com/support/bugreports/). Use the Saved Searches and Watched Bugs tool with the search phrase “Incorrect Code Generation” to obtain a report of known bugs that produce code that might compile and execute, but still produce wrong answers.

The bug reports are an integral part of the documentation for each release. Examine periodically all bug reports for a release, as such reports may identify inconsistencies between the actual behavior of a release you are using and the behavior described in this documentation.

In addition to reviewing bug reports, you should implement a verification and validation strategy to identify potential bugs in your design, code, and tools.



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# Product Overview

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- “Code Generation Technology” on page 1-4
- “Code Generation Extensions” on page 1-5
- “Prerequisite Knowledge” on page 1-6
- “Target Environments and Applications” on page 1-8
- “Algorithm Development Workflows” on page 1-14

## Product Description

### **Generate C and C++ code optimized for embedded systems**

Embedded Coder<sup>®</sup> generates readable, compact, and fast C and C++ code for use on embedded processors, on-target rapid prototyping boards, and microprocessors used in mass production. Embedded Coder enables additional MATLAB<sup>®</sup> Coder<sup>™</sup> and Simulink<sup>®</sup> Coder configuration options and advanced optimizations for fine-grain control of the generated code's functions, files, and data. These optimizations improve code efficiency and facilitate integration with legacy code, data types, and calibration parameters used in production. You can incorporate a third-party development environment into the build process to produce an executable for turnkey deployment on your embedded system.

Embedded Coder offers built-in support for AUTOSAR and ASAP2 software standards. It also provides traceability reports, code interface documentation, and automated software verification. Support for industry standards is available through IEC Certification Kit (for ISO 26262 and IEC 61508) and DO Qualification Kit (for DO-178).

Learn more about MathWorks support for certification in automotive, aerospace, and industrial automation.

### **Key Features**

- Optimization and code configuration options that extend MATLAB Coder and Simulink Coder
- Storage class, type, and alias definition using Simulink data dictionary capabilities
- Processor-specific code optimization
- Multirate, multitask, and multicore code execution with or without an RTOS
- Code verification, including SIL and PIL testing, custom comments, and code reports with tracing of models to and from code and requirements
- Integration with Texas Instruments<sup>™</sup> Code Composer Studio<sup>™</sup>, Analog Devices<sup>™</sup> VisualDSP++<sup>®</sup>, and other third-party embedded development environments

- Standards support, including ASAP2, AUTOSAR, DO-178, IEC 61508, ISO 26262, and MISRA-C

## Code Generation Technology

MathWorks® code generation technology produces C code and executable programs for algorithms that you model programmatically with MATLAB or graphically in the Simulink environment. You can generate code for any MATLAB functions, Simulink blocks, and Stateflow® charts that are useful for real-time or embedded applications. The generated source code and executable programs for floating-point algorithms match the functional behavior of MATLAB code execution and Simulink simulations to high degrees of fidelity. Using the Fixed-Point Designer™ product, you can generate fixed-point code that provides a bit-wise match to model execution and simulation results. Such broad support and high degrees of accuracy are possible because code generation is tightly integrated with the MATLAB and Simulink execution and simulation engines. The built-in accelerated simulation modes in Simulink use code generation technology.

Code generation technology and related products provide tooling that you can apply to the V-model for system development. The V-model is a representation of system development that highlights verification and validation steps in the development process. For more information about the V-model and how MathWorks code generation technology and related products provide tooling that you can apply to the process, see “V-Model for System Development”.

## Code Generation Extensions

The Embedded Coder product *extends* the MATLAB Coder and Simulink Coder products with features that are important for embedded software development. Using the Embedded Coder product, you can generate code that has the clarity and efficiency of professional handwritten code. For example, you can:

- Generate code that is compact and fast, which is essential for real-time simulators, on-target rapid prototyping boards, microprocessors used in mass production, and embedded systems.
- Customize the appearance of the generated code.
- Optimize generated code for a specific target environment.
- Integrate existing (legacy) applications, functions, and data.
- Enable tracing, reporting, and testing options that facilitate code verification activities.

## Prerequisite Knowledge

In this section...
“MATLAB Users” on page 1-6
“Simulink Users” on page 1-6

### **MATLAB Users**

Be familiar with:

- “MATLAB Coder”
- Code Generation from MATLAB
- MATLAB Function block

If you are familiar with C language constructs and want to learn how to map commonly used C constructs to code generated from MATLAB program design patterns, see “Patterns for C Code”.

### **Simulink Users**

Be familiar with:

- Simulink and Stateflow software to create models or state machines as block diagrams, running such simulations in Simulink, and interpreting output in the MATLAB workspace.
- Generating code and building executable programs from Simulink models.
- High-level programming language concepts applied to embedded, real-time systems.

While you do not need to program in C or other programming languages to create, test, and deploy embedded systems, using Embedded Coder software, emulation and deployment of embedded systems requires familiarity with parameters and design constraints. The Embedded Coder documentation assumes you have a basic understanding of real-time and embedded system concepts, terminology, and environments.



If you have not done so, you should study:

- The tutorials in “Getting Started with Simulink Coder”. The tutorials provide hands-on experience in configuring models for code generation and generating code, setting up a data interface, and integrating external code.
- “Model Architecture and Design” in the Simulink Coder documentation. These sections give a general overview of the architecture and execution of generated code.

If you are familiar with C language constructs and want to learn about how to map commonly used C constructs to code generated from model design patterns that include Simulink blocks, Stateflow charts, and MATLAB function blocks, see “Patterns for C Code”.

## Target Environments and Applications

### In this section...

“About Target Environments” on page 1-8

“Types of Target Environments Supported By Embedded Coder” on page 1-8

“Applications of Supported Target Environments” on page 1-11

### About Target Environments

In addition to generating source code, the code generator produces make or project files to build an executable program for a specific target environment. The generated make or project files are optional. If you prefer, you can build an executable for the generated source files by using an existing target build environment, such as a third-party integrated development environment (IDE). Applications of generated code range from calling a few exported C or C++ functions on a host computer to generating a complete executable program using a custom build process, for custom hardware, in an environment completely separate from the host computer running MATLAB and Simulink.

The code generator provides built-in *system target files* that generate, build, and execute code for specific target environments. These system target files offer varying degrees of support for interacting with the generated code to log data, tune parameters, and experiment with or without Simulink as the external interface to your generated code.

### Types of Target Environments Supported By Embedded Coder

Before you select a system target file, identify the target environment on which you expect to execute your generated code. The most common target environments include environments listed in the following table.

Target Environment	Description
Host computer	<p>The same computer that runs MATLAB and Simulink. Typically, a host computer is a PC or UNIX<sup>®1</sup> environment that uses a non-real-time operating system, such as Microsoft<sup>®</sup> Windows<sup>®</sup> or Linux<sup>®2</sup>. Non-real-time (general purpose) operating systems are nondeterministic. For example, those operating systems might suspend code execution to run an operating system service and then, after providing the service, continue code execution. Therefore, the executable for your generated code might run faster or slower than the sample rates that you specified in your model.</p>
Real-time simulator	<p>A different computer than the host computer. A real-time simulator can be a PC or UNIX environment that uses a real-time operating system (RTOS), such as:</p> <ul style="list-style-type: none"> <li>• xPC Target<sup>™</sup> system</li> <li>• A real-time Linux system</li> <li>• A Versa Module Eurocard (VME) chassis with PowerPC<sup>®</sup> processors running a commercial RTOS, such as VxWorks<sup>®</sup> from Wind River<sup>®</sup> Systems</li> </ul> <p>The generated code runs in real time. The exact nature of execution varies based on the particular behavior of the system hardware and RTOS.</p> <p>Typically, a real-time simulator connects to a host computer for data logging, interactive parameter tuning, and Monte Carlo batch execution studies.</p>
Embedded microprocessor	<p>A computer that you eventually disconnect from a host computer and run as a standalone computer as part of an electronics-based product. Embedded microprocessors range in price and performance, from high-end digital signal processors (DSPs) to process communication signals to inexpensive 8-bit fixed-point microcontrollers in mass production (for example, electronic parts produced in the millions of units). Embedded microprocessors can:</p> <ul style="list-style-type: none"> <li>• Use a full-featured RTOS</li> </ul>

1. UNIX<sup>®</sup> is a registered trademark of The Open Group in the United States and other countries.

2. Linux<sup>®</sup> is a registered trademark of Linus Torvalds.

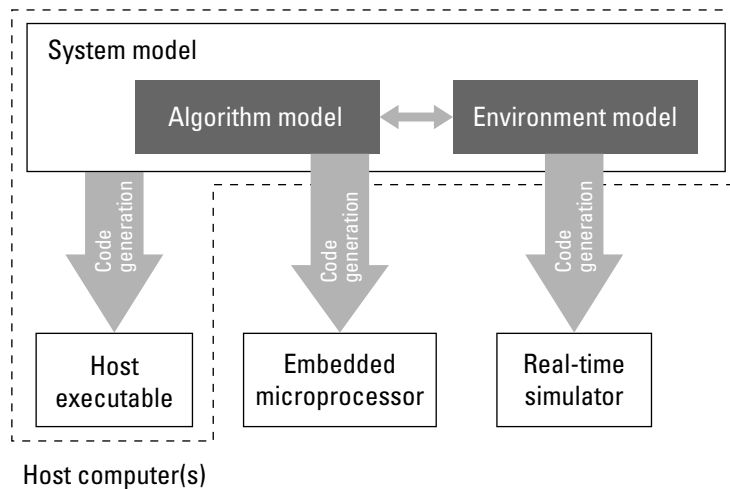
Target Environment	Description
	<ul style="list-style-type: none"> <li>• Be driven by basic interrupts</li> <li>• Use rate monotonic scheduling provided with code generation</li> </ul>

A target environment can:

- Have single- or multiple-core CPUs
- Be a standalone computer or communicate as part of a computer network

In addition, you can deploy different parts of a Simulink model on different target environments. For example, it is common to separate the component (algorithm or controller) portion of a model from the environment (or plant). Using Simulink to model an entire system (plant and controller) is often referred to as closed-loop simulation and can provide many benefits, such as early verification of a component.

The following figure shows example target environments for code generated for a model.



## Applications of Supported Target Environments

The following table lists several ways that you can apply code generation technology in the context of the different target environments.

Application	Description
<b>Host Computer</b>	
“Acceleration”	You apply techniques to speed up the execution of model simulation in the context of the MATLAB and Simulink environments. Accelerated simulations are especially useful when run time is long compared to the time associated with compilation and checking whether the target is up to date.
“Rapid Simulation”	You execute code generated for a model in nonreal time on the host computer, but outside the context of the MATLAB and Simulink environments.
“Shared Object Libraries”	You integrate components into a larger system. You provide generated source code and related dependencies for building a system in another environment or in a host-based shared library to which other code can dynamically link.
“Protect a Referenced Model”	You generate a protected model for use by a third-party vendor in another Simulink simulation environment.
<b>Real-Time Simulator</b>	
“Real-Time System Rapid Prototyping”	You generate, deploy, and tune code on a real-time simulator connected to the system hardware (for example, physical plant or vehicle) being controlled. This design step is crucial for validating whether a component can control the physical system.

<b>Application</b>	<b>Description</b>
“Integration and Reusable Components”	You integrate generated source code and dependencies for components into a larger system that is built in another environment. You can use shared library files for intellectual property protection.
“Real-Time System Rapid Prototyping”	You generate code for a detailed design that you can run in real time on an embedded microprocessor while tuning parameters and monitoring real-time data. This design step allows you to assess, interact with, and optimize code, using embedded compilers and hardware.
<b>Embedded Microprocessor</b>	
“Code Generation”	From a model, you generate code that is optimized for speed, memory usage, simplicity, and possibly, compliance with industry standards and guidelines.
“Software-in-the-Loop (SIL) Simulation”	You execute generated code with your plant model within Simulink to verify conversion of the model to code. You might change the code to emulate target word size behavior and verify numerical results expected when the code runs on an embedded microprocessor. Or, you might use actual target word sizes and just test production code behavior.

<b>Application</b>	<b>Description</b>
“Processor-in-the-Loop (PIL) Simulation”	You test an object code component with a plant or environment model in an open- or closed-loop simulation to verify model-to-code conversion, cross-compilation, and software integration.
Hardware-in-the-loop (HIL) testing	You verify an embedded system or embedded computing unit (ECU), using a real-time target environment.

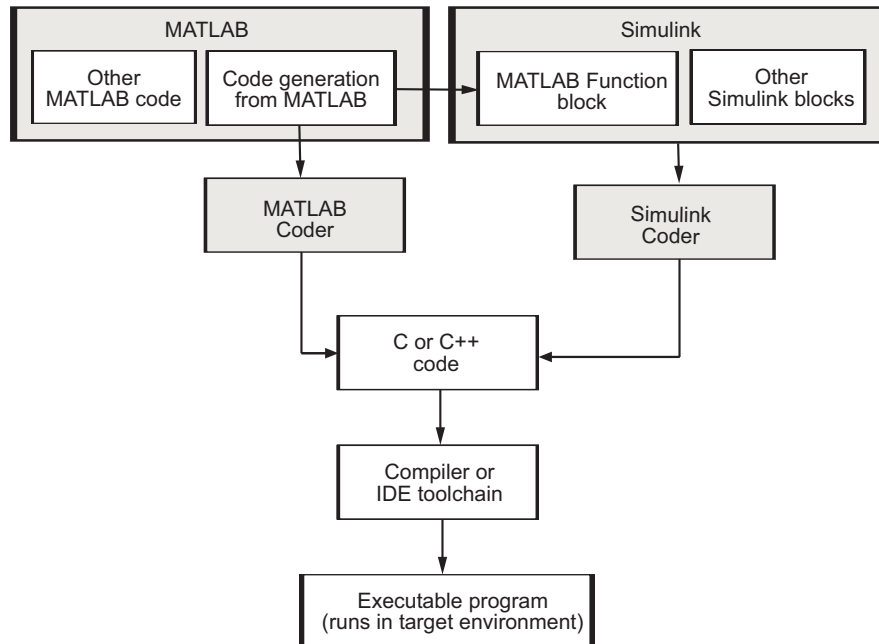
## Algorithm Development Workflows

You can use MathWorks code generation technology to generate standalone C or C++ source code for embedded systems:

- By developing MATLAB algorithms with Code Generation from MATLAB and then generating C/C++ code with the MATLAB Coder and Embedded Coder products
- By developing Simulink models and Stateflow charts and then generating C/C++ code with the Simulink Coder and Embedded Coder products
- By integrating MATLAB code into Simulink models, using Code Generation from MATLAB and the Simulink MATLAB Function block, and then generating C/C++ code with the Simulink Coder and Embedded Coder products

The following figure shows the design and deployment environment options. Although not shown in the figure, other products that support code generation, such as Stateflow software, are available.





The following table summarizes how to generate C or C++ code for each of the approaches and identifies where you can find more information.

<b>If you develop algorithms using...</b>	<b>You generate code by...</b>	<b>For more information, see...</b>
Code generation from MATLAB	Using MATLAB Coder projects Entering the function codegen in the MATLAB Command Window	“Workflow Overview” in the MATLAB Coder documentation.
Simulink and Stateflow	Configuring and initiating code generation for your model or subsystem with the Simulink Configuration Parameters dialog.	“Simulink and Stateflow Model” in the Simulink Coder documentation
Code generation from MATLAB and Simulink	Including MATLAB code in Simulink models or subsystems by using the MATLAB Function block.  To use this block, you can do one of the following: <ul style="list-style-type: none"> <li>• Copy your code into the block.</li> <li>• Call your code from the block by referencing the files on the MATLAB path.</li> </ul>	Code generation from MATLAB documentation  MATLAB Function block in the Simulink documentation

To use MATLAB code and Simulink models for a Model-Based Design project:

- Start by using MATLAB to develop an algorithm for research and early development.
- Later you can integrate the algorithm into a graphical model for system deployment and verification.

Benefits of this approach include:

- Richer system simulation environment
- Ability to verify the MATLAB code

- Simulink Coder and Embedded Coder C/C++ code generation for the model and MATLAB code

If you are familiar with C language constructs and want to learn about how to map commonly used C constructs to code generated from model design patterns that include Simulink blocks, Stateflow charts, and MATLAB functions, see “Patterns for C Code”.



# MATLAB Tutorials

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- “Generate C Code from MATLAB Code” on page 2-2
- “Controlling C Code Style” on page 2-4
- “Generating Reentrant C Code from MATLAB Code” on page 2-9
- “Tracing Between Generated C Code and MATLAB Code” on page 2-18

## Generate C Code from MATLAB Code

In this section...
“About MATLAB® Coder™” on page 2-2
“Getting Started Tutorials” on page 2-3

### About MATLAB Coder

MATLAB Coder generates standalone C and C++ from MATLAB code. The generated source code is portable and readable. MATLAB Coder supports a subset of core MATLAB language features, including program control constructs, functions, and matrix operations. It can generate MEX functions that let you accelerate computationally intensive portions of MATLAB code and verify the behavior of the generated code.

When generating C and C++ code from MATLAB code, follow this workflow.

### How Embedded Coder Works With MATLAB Coder

The Embedded Coder product extends the MATLAB Coder product with features that are important for embedded software development. Using the Embedded Coder add-on product, you can generate code that has the clarity and efficiency of professional handwritten code. For example, you can:

- Generate code that is compact and fast, which is essential for real-time simulators, on-target rapid prototyping boards, microprocessors used in mass production, and embedded systems
- Customize the appearance of the generated code
- Optimize the generated code for a specific target environment
- Enable tracing options that help you to verify the generated code
- Generate reusable, reentrant code

## Getting Started Tutorials

The following tutorials will help you get started with using Embedded Coder to generate code from MATLAB code for embedded system applications.

- “Controlling C Code Style” on page 2-4
- “Generating Reentrant C Code from MATLAB Code” on page 2-9
- “Tracing Between Generated C Code and MATLAB Code” on page 2-18

## Prerequisites

To complete these tutorials, you must install the following products:

- MATLAB
- MATLAB Coder
- Embedded Coder
- C compiler

For a list of supported compilers, see [http://www.mathworks.com/support/compilers/current\\_release/](http://www.mathworks.com/support/compilers/current_release/).

You must set up the C compiler before generating C code. See “Setting Up the C/C++ Compiler” in the MATLAB Coder documentation.

For instructions on installing MathWorks products, see the MATLAB installation documentation for your platform. If you have installed MATLAB and want to check which other MathWorks products are installed, in the MATLAB Command Window, enter `ver` .

## Setting Up Tutorial Files

The tutorial files are available in the following folder: `matlabroot\help\toolbox\ecoder\examples`. To run the tutorials, copy these files to a local folder. Each tutorial provides instructions about which files to copy and how to copy them.

## Controlling C Code Style

In this section...
“About This Tutorial” on page 2-4
“Copying Files Locally” on page 2-5
“Setting Up the MATLAB® Coder™ Project” on page 2-5
“Configuring Build Parameters” on page 2-6
“Generating the C Code” on page 2-7
“Viewing the Generated C Code” on page 2-7
“Key Points to Remember” on page 2-8
“Learn More” on page 2-8

### About This Tutorial

#### Learning Objectives

This tutorial shows you how to:

- Generate code for `if-elseif-else` decision logic as `switch-case` statements.
- Automatically generate C code from your MATLAB code using MATLAB Coder.
- Configure code generation configuration parameters in the MATLAB Coder project.
- Generate a code generation report that you can use to view and debug your MATLAB code.

#### Prerequisites

To complete this tutorial, install the required products and set up your C compiler as described in “Prerequisites” on page 2-3.



## Required Files

Type	Name	Description
Function code	test_code_style.m	MATLAB example that uses if-elseif-else .

To run the tutorial, copy this file to a local folder. For instructions, see “Copying Files Locally” on page 2-5.

## Copying Files Locally

Copy the tutorial files to a local working folder.

- 1 Create a local working folder, for example, `c:\ecoder\work`.
- 2 Change to the `matlabroot\help\toolbox\ecoder\examples` folder. At the MATLAB command line, enter:

```
cd(fullfile(docroot, 'toolbox', 'ecoder', 'examples'))
```

- 3 Copy the file `test_code_style.m` to your local working folder.

Your work folder now contains the file you need to complete this tutorial.

## Setting Up the MATLAB Coder Project

- 1 Set your MATLAB current folder to the work folder that contains the file for this tutorial. At the MATLAB command line, enter:

```
cd work
```

where *work* is the full path of the work folder containing your files.

- 2 At the MATLAB command line, enter


```
coder -new code_style.prj
```

By default, the project opens in the MATLAB workspace on the right side.

- 3 On the project **Overview** tab, click the **Add files** link and browse to the file `test_code_style.m` and then click **OK** to add the file to the project.
- 4 Define the type of input `x`.

### **Why Specify an Input Definition?**

Because C and C++ are statically-typed languages, MATLAB Coder must determine the properties of all variables in the MATLAB files at code generation time. For more information, see “Primary Function Input Specification” in the MATLAB Coder documentation.

On the **Overview** tab, select the input parameter `x` and then click the **Actions** icon to the right of this parameter to open the context menu. 

- 5 From the menu, select **Define Type**.
- 6 In the **Define Type** dialog box, set **Class** to `int16`. Click **OK**.

---

**Note** The **Convert if-elseif-else patterns to switch-case statements optimization** works only for integer and enumerated type inputs.

---

## **Configuring Build Parameters**

- 1 In the MATLAB Coder project, click the **Build** tab.
- 2 On the **Build** tab, set the **Output type** to `C/C++ Static Library`.
- 3 On the **Build** tab, click the **More settings** link to view the project settings.
- 4 In the **Project Settings** dialog box, click the **Code Appearance** tab.
- 5 On the **Code Appearance** tab, select **Convert if-elseif-else patterns to switch-case statements**.
- 6 On the **Debugging** tab, verify that **Always create a code generation report** is selected and then close the dialog box.

## Generating the C Code

On the **Build** tab, click the **Build** button.

The Build progress dialog box opens. When the build is complete, MATLAB Coder generates a C static library, `test_code_style.lib`, and C code in the `/codegen/lib/test_code_style` subfolder. Because you selected report generation, MATLAB Coder provides a link to the report on the **Results** tab.

## Viewing the Generated C Code

MATLAB Coder generates C code in the file `test_code_style.c`.

To view the generated code:

- 1** On the **Build** tab **Results** pane, click the View report link to open the code generation report.
- 2** In the report, click the **C code** tab.
- 3** On this tab, click the `test_code_style.c` link.

MATLAB Coder converts the `if-elseif-else` pattern to the following `switch-case` statements:

```
switch (x) {
    case 1:
        y = 1.0;
        break;

    case 2:
        y = 2.0;
        break;

    case 3:
        y = 3.0;
        break;

    default:
        y = 4.0;
        break;
```

}

## Key Points to Remember

- Use the **More settings** option on the MATLAB Coder project **Build** tab to open the **Project Settings** dialog box where you can configure code generation options.
- Use the **View Report** option on the MATLAB Coder project **Build** tab to open the code generation report.

## Learn More

To...	See...
Learn how to create and set up a MATLAB Coder project	“MATLAB Coder Project Set Up Workflow”
Learn how to generate C/C++ code from MATLAB code at the command line	codegen

# Generating Reentrant C Code from MATLAB Code

## In this section...

- “About This Tutorial” on page 2-9
- “Copying Files Locally” on page 2-10
- “About the Example” on page 2-11
- “Providing a main Function” on page 2-12
- “Configuring Build Parameters” on page 2-15
- “Generating the C Code” on page 2-15
- “Viewing the Generated C Code” on page 2-15
- “Running the Code” on page 2-16
- “Key Points to Remember” on page 2-17
- “Learn More” on page 2-17

## About This Tutorial

### Learning Objectives

This tutorial shows you how to:

- Generate reentrant code from MATLAB code that uses no persistent or global data

---

**Note** This example runs on Windows only.

---

- Automatically generate C code from your MATLAB code.
- Define function input properties at the command line.
- Specify code generation properties.
- Generate a code generation report that you can use to view and debug your MATLAB code.

## Prerequisites

To complete this tutorial, install the required products and set up your C compiler as described in “Prerequisites” on page 2-3

## Required Files

Type	Name	Description
Function code	<code>matrix_exp.m</code>	MATLAB Function that computes matrix exponential of the input matrix using Taylor series and returns the computed output.
C main function	<code>main.c</code>	Calls the reentrant code.

To run the tutorial, copy these files to a local folder. For instructions, see “Copying Files Locally” on page 2-10.

## Copying Files Locally

Copy the tutorial files to a local working folder.

- 1 Create a local working folder, for example, `c:\ecoder\work`.
- 2 Change to the `matlabroot\help\toolbox\ecoder\examples` folder. At the MATLAB command line, enter:

```
cd(fullfile(docroot, 'toolbox', 'ecoder', 'examples'))
```

- 3 Copy the `reentrant_win` folder to your local working folder.

Your work folder now contains the files you need to complete this tutorial.

- 4 Set your MATLAB current folder to the work folder that contains your files for this tutorial. At the MATLAB command line, enter:

```
cd work
```

where *work* is the full path of the work folder containing your files.

## About the Example

This example requires libraries that are specific to the Microsoft Windows operating system and, therefore, runs only on Windows platforms. It is a simple, multithreaded example that uses no persistent or global data. Two threads call the MATLAB function `matrix_exp` with different sets of input data.

## Contents of `matrix_exp.m`

```
function Y = matrix_exp(X) %#codegen
%
% The function matrix_exp computes matrix exponential of
% the input matrix using Taylor series and returns the
% computed output.
E = zeros(size(X));
F = eye(size(X));
k = 1;
while norm(E+F-E,1) > 0
    E = E + F;
    F = X*F/k;
    k = k+1;
end
Y = E;
```

When you generate reusable, reentrant code, `codegen` supports dynamic allocation of function variables that are too large for the stack, as well as persistent and global variables. `codegen` generates a header file, `primary_function_name_types.h`, which you must include when using the generated code. This header file contains the following structures:

- `primary_function_nameStackData`

Contains the user allocated memory. You must pass a pointer to this structure as the first parameter to all functions that use it either directly, because the function uses a field in the structure, or indirectly, because the function passes the structure to a called function.

If the algorithm uses persistent or global data, the *primary\_function\_nameStackData* structure also contains a pointer to the *primary\_function\_namePersistentData* structure. Including this pointer means that you have to pass only one parameter to each calling function.

- *primary\_function\_namePersistentData*

If your algorithm uses persistent or global variables, `codegen` provides a separate structure for them and adds a pointer to this structure to the memory allocation structure. Having a separate structure for persistent and global variables allows you to allocate memory for these variables once and share them with all threads if desired. However, if there is no communication between threads, you can choose to allocate memory for these variables per thread or per application.

## Providing a main Function

To call the reentrant code, you must provide a main function that:

- Includes the generated header file `matrix_exp.h`. This file includes the generated header file, `matrix_exp_types.h`.
- For each thread, allocates memory for stack data.
- Calls the `matrix_exp_initialize` housekeeping function. For more information, see “Calling Initialize and Terminate Functions” in the MATLAB Coder documentation.
- Calls `matrix_exp`.
- Calls `matrix_exp_terminate`.
- Frees the memory used for stack data.



## Contents of main.c

```
#include <stdio.h>
#include <stdlib.h>
#include <windows.h>
#include "matrix_exp.h"
#include "matrix_exp_initialize.h"
#include "matrix_exp_terminate.h"
#include "rtwtypes.h"
#define NUMELEMENTS (160*160)

typedef struct {
    real_T in[NUMELEMENTS];
    real_T out[NUMELEMENTS];
    matrix_expStackData* spillData;
} IODATA;

/* The thread_function calls the matrix_exp function written in MATLAB */
DWORD WINAPI thread_function(PVOID dummyPtr) {
    IODATA *myIOData = (IODATA*)dummyPtr;
    matrix_exp_initialize();
    matrix_exp(myIOData->spillData, myIOData->in, myIOData->out);
    matrix_exp_terminate();
    return 0;
}

void main() {
    HANDLE thread1, thread2;
    IODATA data1;
    IODATA data2;
    int32_T i;

    /*Initializing data for passing to the 2 threads*/
    matrix_expStackData* sd1 = (matrix_expStackData*)calloc(1,sizeof(matrix_expStackData));
    matrix_expStackData* sd2 = (matrix_expStackData*)calloc(1,sizeof(matrix_expStackData));

    data1.spillData = sd1;
    data2.spillData = sd2;
```

```
for (i=0;i<NUMELEMENTS;i++) {
    data1.in[i] = 1;
    data1.out[i] = 0;
    data2.in[i] = 1.1;
    data2.out[i] = 0;
}

/*Initializing the 2 threads and passing data to the thread functions*/
printf("Starting thread 1...\n");
thread1 = CreateThread(NULL , 0, thread_function, (PVOID) &data1, 0, NULL);
if (thread1 == NULL){
    perror( "Thread 1 creation failed.");
    exit(EXIT_FAILURE);
}

printf("Starting thread 2...\n");
thread2 = CreateThread(NULL, 0, thread_function, (PVOID) &data2, 0, NULL);
if (thread2 == NULL){
    perror( "Thread 2 creation failed.");
    exit(EXIT_FAILURE);
}

/*Wait for both the threads to finish execution*/
if (WaitForSingleObject(thread1, INFINITE) != WAIT_OBJECT_0){
    perror( "Thread 1 join failed.");
    exit(EXIT_FAILURE);
}

if (WaitForSingleObject(thread2, INFINITE) != WAIT_OBJECT_0){
    perror( "Thread 2 join failed.");
    exit(EXIT_FAILURE);
}

free(sd1);
free(sd2);

printf("Finished Execution!\n");
exit(EXIT_SUCCESS);
}
```

## Configuring Build Parameters

You enable generation of reentrant code using a code generation configuration object.

- 1 Create a configuration object.

```
e = coder.config('exe', 'ecoder', true);
```

This command creates a `coder.EmbeddedCodeConfig` object which contains all the configuration parameters that the `codegen` function needs to generate standalone C/C++ static libraries and executables for an embedded target.

- 2 Enable reentrant code generation.

```
e.MultiInstanceCode = true;
```

## Generating the C Code

Call the `codegen` function to generate C code, with the following options:

- `-config` to pass in the code generation configuration object `e`.
- `main.c` to include this file in the compilation.
- `-report` to create a code generation report.
- `-args` to specify an example input with the class, size, and complexity.

```
codegen -config e main.c -report matrix_exp.m -args ones(160,160)
```

`codegen` generates a C executable, `matrix_exp.exe`, in the current folder and C code in the `/codegen/exe/matrix_exp` subfolder. Because you selected report generation, `codegen` provides a link to the report.

## Viewing the Generated C Code

`codegen` generates a header file `matrix_exp_types.h`, which defines the `matrix_expStackData` global structure. This structure contains local variables that are too large to fit on the stack.

To view this header file:

- 1 Click the **View report** link to open the code generation report.
- 2 In the report, click the **C code** tab.
- 3 On this tab, click the link to `matrix_exp_types.h`.

```
/*
 * matrix_exp_types.h
 *
 * MATLAB Coder code generation for function 'matrix_exp'
 */
#ifndef __MATRIX_EXP_TYPES_H__
#define __MATRIX_EXP_TYPES_H__

/* Type Definitions */
typedef struct {
    struct {
        real_T F[25600];
        real_T Y[25600];
    } f0;
} matrix_expStackData;

#endif
/* End of code generation (matrix_exp_types.h) */
```

## Running the Code

Call the code, first verifying that the example is running on Windows platforms.

```
% This example can only be run on Windows platforms
if ~ispc
    error('This example requires Windows-specific libraries and can only be run on
    Windows.');
```

```
end
system('matrix_exp.exe')
```

The executable runs and reports completion.

## Key Points to Remember

- Create a main function that
  - Includes the generated header file, *primary\_function\_name\_types.h*. This file defines the *primary\_function\_nameStackData* global structure. This structure contains local variables that are too large to fit on the stack.
  - For each thread, allocates memory for stack data.
  - Calls *primary\_function\_name\_initialize* .
  - Calls *primary\_function\_name*.
  - Calls *primary\_function\_name\_terminate*.
  - Frees the memory used for stack data.
- Use the `-config` option to pass the code generation configuration object to the `codegen` function.
- Use the `-args` option to specify input parameters at the command line.
- Use the `-report` option to create a code generation report.

## Learn More

To...	See...
Learn more about the generated code API	“Generated Code API”
Call reentrant code with no persistent or global data on UNIX	“Call Reentrant Code with No Persistent or Global Data (UNIX Only)”
Call reentrant code with persistent data on Windows	“Call Reentrant Code — Multithreaded with Persistent Data (Windows Only)”
Call reentrant code with persistent data on UNIX	“Call Reentrant Code — Multithreaded with Persistent Data (UNIX Only)”

## Tracing Between Generated C Code and MATLAB Code

In this section...
“About This Tutorial” on page 2-18
“Copying Files Locally” on page 2-19
“Configuring Build Parameters” on page 2-20
“Generating the C Code” on page 2-20
“Viewing the Generated C Code” on page 2-20
“Tracing Back to the Source MATLAB Code” on page 2-21
“Key Points to Remember” on page 2-21
“Learn More” on page 2-22

### About This Tutorial

#### Learning Objectives

This tutorial shows you how to:

- Generate code that includes the MATLAB source code as comments.
- Include the function help text in the function header of the generated code.
- Use the code generation report to trace from the generated code to the source code.

#### Prerequisites

To complete this tutorial, install the required products and set up your C compiler as described in “Prerequisites” on page 2-3

## Required File

Type	Name	Description
Function code	polar2cartesian.m	Simple MATLAB function that contains a comment

To run the tutorial, copy this file to a local folder. For instructions, see “Copying Files Locally” on page 2-19.

## Copying Files Locally

Copy the tutorial file to a local working folder.

- 1 Create a local working folder, for example, `c:\ecoder\work`.
- 2 Change to the `matlabroot\help\toolbox\ecoder\examples` folder. At the MATLAB command line, enter:

```
cd(fullfile(docroot, 'toolbox', 'ecoder', 'examples'))
```

- 3 Copy the `polar2cartesian.m` file to your local working folder.

Your work folder now contains the file you need to complete this tutorial.

- 4 Set your MATLAB current folder to the work folder that contains the file for this tutorial. At the MATLAB command line, enter:

```
cd work
```

where *work* is the full path of the work folder containing your files.

## Contents of polar2cartesian.m

```
function [x y] = polar2cartesian(r,theta)
%#codegen
% Convert polar to Cartesian
x = r * cos(theta);
y = r * sin(theta);
```

## Configuring Build Parameters

- 1 Create a `coder.EmbeddedCodeConfig` code generation configuration object.

```
cfg = coder.config('lib', 'ecoder', true);
```

- 2 Enable the `MATLABSourceCode` option to include MATLAB source code as comments in the generated code and the function signature in the function banner.

```
cfg.MATLABSourceComments = true;
```

- 3 Enable the `MATLABFcnDesc` option to include the function help text in the function banner.

```
cfg.MATLABFcnDesc = true;
```

## Generating the C Code

Call the `codegen` function to generate C code, with the following options:

- `-config` to pass in the code generation configuration object `cfg`.
- `-report` to create a code generation report.
- `-args` to specify the class, size, and complexity of the input parameters.

```
codegen -config cfg -report polar2cartesian -args {0, 0}
```

`codegen` generates a C static library, `polar2cartesian.lib`, and C code in the `/codegen/lib/polar2cartesian` subfolder. Because you selected report generation, `codegen` provides a link to the report.

## Viewing the Generated C Code

`codegen` generates C code in the file `polar2cartesian.c`.

To view the generated code:

- 1 Click the `View report` link to open the code generation report.
- 2 In the report, click the **C code** tab.



**3** On this tab, click the `polar2cartesian.c` link.

Examine the generated code. The function help text `Convert polar to Cartesian` appears in the function header. The source code appears as comments in the generated code.

```

/*
 * function [x y] = polar2cartesian(r,theta)
 * Convert polar to Cartesian
 */
void straightline(real_T r, real_T theta, ...
    real_T *x, real_T *y)
{
    /* 'polar2cartesian:4' x = r * cos(theta); */
    *x = r * cos(theta);
    /* 'polar2cartesian:5' y = r * sin(theta); */
    *y = r * sin(theta);
}

```

## Tracing Back to the Source MATLAB Code

To trace back to the source code, click any traceability tag.

For example, to view the MATLAB code for the C code, `x = r * cos(theta);`, click the `'polar2cartesian:4'` traceability tag.

The source code file `polar2cartesian.m` opens in the MATLAB editor with line 4 highlighted.

## Key Points to Remember

- Create a `coder.EmbeddedCodeConfig` configuration object and enable the:
  - `MATLABSourceCode` option to include MATLAB source code as comments in the generated code and the function signature in the function banner
  - `MATLBFcnDesc` option to include the function help text in the function banner
- Use the `-config` option to pass the code generation configuration object to the `codegen` function.

- Use the `-report` option to create a code generation report.
- Use the `-args` option to specify the class, size, and complexity of input parameters.

## Learn More

To...	See...
Learn more about code traceability	“About Code Traceability”
Learn about the location of comments in the generated code	“Location of Comments in Generated Code”
See traceability limitations	“Traceability Limitations”

# Simulink Tutorials

---

- “Generate C Code from Simulink Models” on page 3-2
- “Configure Model and Generate Code” on page 3-5
- “Control Appearance of Generated Code” on page 3-15
- “Configure Data Interface” on page 3-21
- “Partition and Export Functions” on page 3-29
- “Integrate Generated Code into External Environment” on page 3-43
- “Verify Generated Code” on page 3-52
- “Evaluate Generated Code” on page 3-62

## Generate C Code from Simulink Models

In this section...
“Tutorials” on page 3-2
“Prerequisites” on page 3-3
“Third-Party Software” on page 3-3
“Required Files” on page 3-3

### Tutorials

The following tutorials are based on the throttle controller example model described in “Model and Test Environment” in the Simulink Coder documentation. The tutorials will help you get started with using Embedded Coder to generate code from Simulink models and subsystems for embedded system applications.

- “Configure Model and Generate Code” on page 3-5
- “Configure Data Interface” on page 3-21
- “Control Appearance of Generated Code” on page 3-15
- “Partition and Export Functions” on page 3-29
- “Integrate Generated Code into External Environment” on page 3-43
- “Verify Generated Code” on page 3-52
- “Evaluate Generated Code” on page 3-62

Each tutorial focuses on a specific aspect of code generation or integration for embedded systems and is self-contained. Use only the tutorials that apply to your needs.

Each tutorial uses a unique Simulink model and data set. As you proceed through the tutorials, you save each model after you have worked on it, preserving your modifications to the model and model data for future examination. To prevent any errors from carrying over to the next tutorial, begin the next tutorial by opening a new model and loading new data.

## Prerequisites

You must know how to:

- **MathWorks products**
  - Read, write, and apply MATLAB scripts
  - Create Simulink models
  - Include Stateflow charts in Simulink models
  - Run Simulink simulations and evaluate the results
- **C programming**
  - Use C data types and storage classes
  - Use function prototypes and call functions
  - Compile a C function
- **Metrics for evaluating embedded software**
  - Evaluate code readability
  - Evaluate RAM/ROM usage
  - Evaluate system execution performance

## Third-Party Software

To compile and build generated code for the integration and testing tutorials, you can use an Integrated Development Environment (IDE) or equivalent tools such as command-line compilers and makefiles. Appendix A, Appendix A, “Installing and Using IDE” describes how to install and use the Eclipse™ IDE for C/C++ Developers and the Cygwin™ debugger for integrating and testing your generated code.

## Required Files

Each tutorial uses a unique example model file and data set.

- Before you use each example file, place a copy in a writable location on your MATLAB path. Proceed through the tutorials from this location.
- As you proceed through a tutorial, save your changes for future examination.

- To avoid potentially introducing errors into the next tutorial, begin each tutorial by opening a new model and loading new data.

# Configure Model and Generate Code

**In this section...**

“About this Tutorial” on page 3-5

“Configure Model for Code Generation” on page 3-6

“Generate Code” on page 3-11

“Review Generated Code” on page 3-12

“Key Points” on page 3-13

“Learn More” on page 3-14

## About this Tutorial

### Learning Objectives

- Configure a model for generating code for an embedded system.
- Apply model-checking tools to discover conditions and configuration settings that can result in generation of inaccurate or inefficient code.
- Generate code optimized for an embedded system from a model.
- Locate and identify generated code files.
- Review generated code.

### Prerequisites

- Completed “Model and Test Environment” and “Configure Model and Generate Code” in the Simulink Coder documentation

### Required File

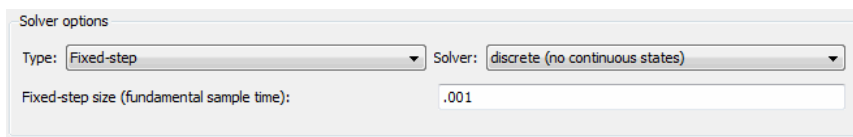
Model `rtwdemo_throttlecntrl_configert`

## Configure Model for Code Generation

Model configuration parameters determine the method for generating the code and the resulting format. When generating code for an embedded system, model configuration can be extremely complex. At a minimum, in addition to the solver type and system target file (STF), configure the model for the hardware implementation and optimizations that align with the system application.

- 1 Open model `rtwdemo_throttlecntrl_configert`. Save a copy as `throttlecntrl_configert` in a writable location on your MATLAB path.
- 2 In the Configuration Parameters dialog box, configure the solver. To generate code, the model must be configured to use a fixed-step solver. The following table shows the solver settings for this example.

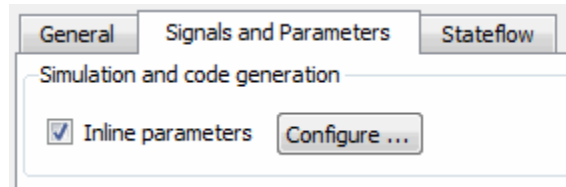
Parameter	Setting	In Generated Code
Type	Fixed-step	Maintains a constant (fixed) step size, which is required for code generation
Solver	discrete (no continuous states)	Applies a fixed-step integration technique for computing the state derivative of the model
Fixed-step size	.001	Sets the base rate; must be the lowest common multiple of all rates in the system



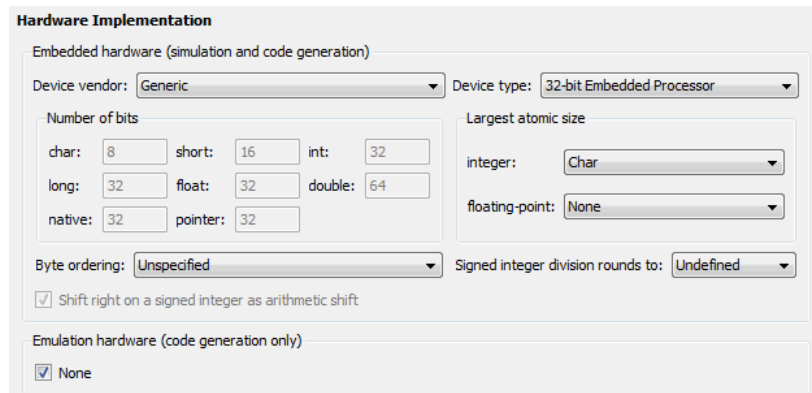
- 3 Open **Optimization > Signals and Parameters** and select **Inline parameters**. When this parameter is set, the code generator optimizes the code by replacing model parameters with constant values. Unless a model



is still under development, consider using this setting when generating code for an embedded system.



- 4 Open the **Hardware Implementation** pane. Use parameters on this pane to specify the device type, word size, and byte ordering of the target hardware. Assume that the throttle controller model targets a generic 32-bit embedded processor. Set **Device type** to **32-bit Embedded Processor**.



- 5 Open the **Code Generation > General** pane. Set the **System target file** parameter to the embedded real-time target file, `ert.tlc`. The code generator uses this target file to generate code that is optimized for embedded system deployment.

The list of **Code Generation** subpanes expands to include:

- **Verification**
- **Code Style**
- **Templates**

- **Code Placement**
  - **Data Type Replacement**
  - **Memory Sections**
- 6 Set code generation parameters based on your application objectives. Configuring a model to meet specific objectives (requirements) for code generation can be an extremely complex, time consuming task. The Code Generation Advisor simplifies this task by allowing you to select and prioritize one or more of the following objectives:
- Execution efficiency
  - ROM efficiency
  - RAM efficiency
  - Traceability
  - Safety precaution
  - Debugging
  - MISRA-C:2004 guidelines

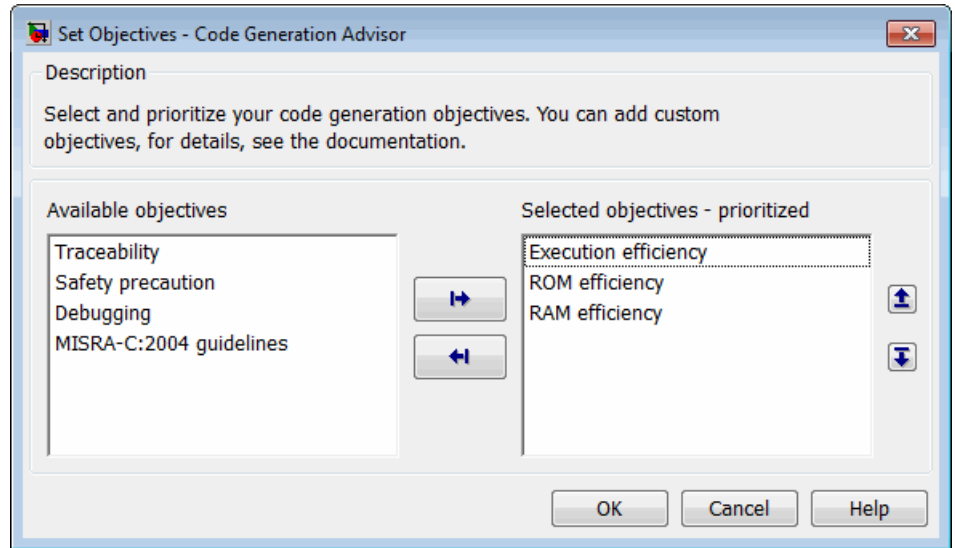
Each objective includes a set of Code Generation Advisor checks that you can use to:

- Review the model configuration parameters against the recommended values of the objectives.
- Verify that the model configuration parameters are set to create code that meets your model objectives.

Some objectives recommend different parameter settings and include different checks in the Code Generation Advisor. When objectives conflict, the priorities of the selected objectives determine which recommendations and checks the advisor presents.

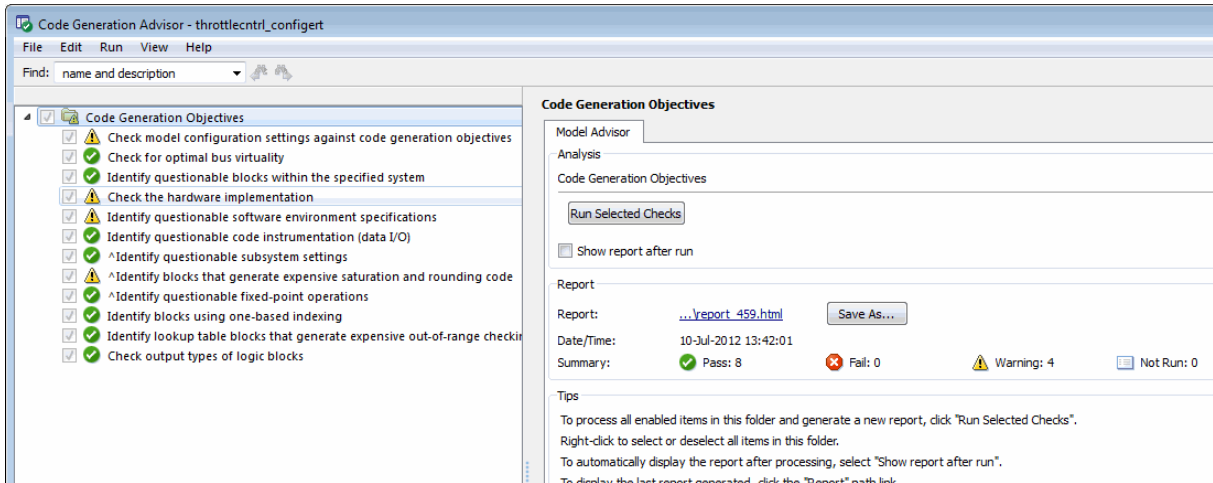
For this tutorial, configure the model for execution and memory efficiency:

- a On the **Code Generation** pane, click **Set objectives**. The Set Objectives dialog box opens.
- b Select and prioritize categories **Execution efficiency**, **ROM efficiency**, and then **RAM efficiency** as shown below.



- 7** Review the model against the selected objectives by using the Code Generation Advisor.
  - a** On the **Code Generation** pane, click **Check model**. A System Selector dialog box opens.
  - b** In the System Selector dialog box, select `throttlecenr1_configrt` and click **OK**.

The Code Generation Advisor dynamically creates and runs a list of checks based on the selection and prioritization of the objectives. This task might take a few minutes.



- c Evaluate the warning condition flagged for the first check in the report, which reviews configuration parameter settings and recommends values based on the objectives.

Select the first check and click **Modify Parameters** to set parameters to recommended values. Then, click **Run This Check** to rerun the check. The warning symbol should disappear.

- d Select hardware implementation check, which is the second check flagged with a warning. This check identifies inconsistencies and incomplete specification of hardware attributes, which can lead to inefficient or incorrect code for the target hardware.

Under Recommended Action, the report suggests that you specify byte ordering and signed integer division rounding for your target hardware. For this tutorial, assume you are using a target that supports both big-endian and little-endian byte ordering. Therefore, **Byte ordering** can remain **Unspecified**. However, you should click the **Signed integer division rounding** link and set the **Signed integer division rounds to** parameter to Zero (the most common behavior), and rerun the check. Note that only the warning for byte ordering remains.

- e The third and fourth checks flagged as warnings concern arithmetic exceptions for integer division in generated code. Assume that you verified that your model cannot cause exceptions in division operations,

and select **Optimization > Remove code that protects against division arithmetic exceptions**. Update the model diagram and rerun the checks. The warnings should disappear.

**f** Close the Code Generation Advisor window.

For more information, see “Determine Model Configuration for Specified Objectives”.

**8** Save the model and the configuration parameter settings as a MATLAB function.

**a** In the Model Explorer window, select `throttlecntrl_configert` in the left pane.

**b** Right-click and select **Configuration > Export Active Configuration**. The Export Active Configuration to File dialog box opens.

**c** Save the file as `throttlecntrlModelErtConfig.m`.

For more information, see “Save a Configuration Set” and “Load a Saved Configuration Set” in the Simulink documentation.

**9** Close the Model Explorer. Save and close the model.

## Generate Code

**1** Open model `throttlecntrl_configert`.

**2** In the Configuration Parameters dialog box, select **Code Generation > Report > Static code metrics**. This setting includes static code metrics in the HTML code generation report. The static code metrics provides metrics on source files, global variables, and functions.

**3** In the Configuration Parameters dialog box, select **Code Generation > Generate code only** (if not already selected).

**4** Click **Generate code** and watch the messages that are displayed in the MATLAB Command Window. The code generator produces standard C and header files and an HTML code generation report. The code generator places the files in a *build folder*, a subfolder named `throttlecntrl_configert_ert_rtw` under your current working folder. The subfolder name is the model name ending with the string `_ert_rtw`.

The resulting code, while computationally efficient, is not yet organized for integration into a production environment.

## Review Generated Code

- 1 From the generated HTML code generation report or the MATLAB Editor, open the generated `throttlecntrl_configert.c` file in the build folder and review the code. Note the following:
  - Identification, version, timestamp, and configuration comments.
  - Data definitions.
  - Controller code is in one function, `throttlecntrl_configert_step`.
  - Operations of multiple blocks are in one equation.
  - Generated data structures (for example, `throttlecntrl_configert_U.pos_rqst`) define all data.
  - `throttlecntrl_configert_initialize` and `throttlecntrl_configert_terminate` functions contain no code.
- 2 From the generated HTML code generation report, select the **Static Code Metrics Report** in the **Contents** section. Note the file statistics, size of the largest global variables, and function call paths that require the largest stack size.
- 3 Close the throttle controller model.

Consider examining the following files by clicking the links in the HTML report, or by exploring other generated files in the build folder.

File	Description
<code>throttlecntrl_configert.c</code>	C file that contains step and initialization functions
<code>throttlecntrl_configert_data.c</code>	C file that assigns values to generated data structures
<code>ert_main.c</code>	Example main module that includes a simple scheduler

File	Description
<code>throttlecntrl_configert.h</code>	Header file that defines data structures
<code>throttlecntrl_configert_private.h</code>	Header file that defines data used only by the generated code
<code>throttlecntrl_configert_types.h</code>	Header file that defines the model data structure

For more information about these and other generated files, see “Generate Code Modules”.

## Key Points

- To generate code for an embedded system, you must at least change the model configuration to specify:
  - A fixed-step solver
  - Hardware settings that match the target hardware specifications
  - ERT system target format
  - Configuration objectives that align with application requirements
- Consider configuring the model with parameter inlining enabled if C code debugging is not required.
- You can check and modify the configuration of a model to best align with application objectives by using the Code Generation Advisor.
- You can save a model configuration for future use or for applying it to another model. Use the Export Active Configuration dialog box, available by right clicking on the model in the Model Explorer.
- Before generating code, consider checking a model with the Model Advisor.
- The code generator places generated files in a subfolder (`throttlecntrl_configert_ert_rtw`) of your working folder.
- Review the static code metrics report to check that possible memory usage is within your requirements.

### **Learn More**

- “Configuration”
- “Determine Model Configuration for Specified Objectives”
- 
- “Save a Configuration Set” and “Load a Saved Configuration Set” in the Simulink documentation.
- “Consult the Model Advisor” in the Simulink documentation.
- Generate a Static Code Metrics Report for Code Reviews
- “Source Code Generation”



# Control Appearance of Generated Code

**In this section...**

“About this Tutorial” on page 3-15

“Customize Code Comments” on page 3-16

“Customize Appearance of Identifiers” on page 3-18

“Customize Code Style” on page 3-19

“Key Points” on page 3-20

“Learn More” on page 3-20

## About this Tutorial

### Learning Objectives

Control and customize the following aspects of generated code appearance to optimize the code, simplify maintenance, improve code readability, or comply with company code conventions and style:

- Comments
- Identifiers (symbols)
- Style (for example, conversion of `if-elseif-else` patterns to `switch-case` statements)

### Prerequisites

You are able to:

- Open and modify Simulink models and subsystems
- Set block properties
- Set model configuration parameters
- Read C code

## Required File

Model `rtwdemo_throttlecntrl_codeappearance`

## Customize Code Comments

- 1 Open model `rtwdemo_throttlecntrl_codeappearance`. Save a copy as `throttlecntrl_codeappearance` in a writable location on your MATLAB path.
- 2 Generate code and examine the comments in the generated file `throttlecntrl_codeappearance.c`.
- 3 Add descriptions to the properties for the three model Inport blocks. For each block, right-click, select Block properties, and enter the descriptions listed in the following table.

For Inport Block...	Add Description...
<code>pos_rqst</code>	Throttle position request input for PI controller subsystems
<code>fbk_1</code>	Feedback input for PI controller subsystem <code>PI_ctrl_1</code>
<code>fbk_2</code>	Feedback input for PI controller subsystem <code>PI_ctrl_2</code>

- 4 Open the **Code Generation > Comments** pane of the Configuration Parameters dialog box and explore the available options.
- 5 Select the **Simulink block descriptions** parameter.
- 6 Generate code and examine the file `throttlecntrl_codeappearance.c`. Specifically, compare the following before and after code fragments:

Before

```
/* Sum: '<S2>/Sum2' incorporates:
 * Inport: '<Root>/fbk_1'
 * Inport: '<Root>/pos_rqst'
 */
```

```

rtb_Sum3 = (*pos_rqst) - my_throttlecntrl_codeappearan_U.fbk_1;
.
.
.
/* Sum: '<S3>/Sum2' incorporates:
 * Inport: '<Root>/fbk_2'
 * Inport: '<Root>/pos_rqst'
 */
rtb_Sum3 = (*pos_rqst) - fbk_2;

```

### After

```

/* Sum: '<S2>/Sum2' incorporates:
 * Inport: '<Root>/fbk_1'
 * Inport: '<Root>/pos_rqst'
 *
 * Block description for '<Root>/fbk_1':
 * Feedback input for PI controller subsystem PI_ctrl_1
 *
 * Block description for '<Root>/pos_rqst':
 * Throttle position request input for PI controller subsystems
 */
rtb_Sum3 = (*pos_rqst) - my_throttlecntrl_codeappearan_U.fbk_1;
.
.
.
/* Sum: '<S3>/Sum2' incorporates:
 * Inport: '<Root>/fbk_2'
 * Inport: '<Root>/pos_rqst'
 *
 * Block description for '/fbk_2':
 * Feedback input for PI controller subsystem PI_ctrl_2
 *
 * Block description for '<Root>/pos_rqst':
 * Throttle position request input for PI controller subsystems
 */
rtb_Sum3 = (*pos_rqst) - fbk_2;

```

### 7 Close the code and model files.

For more information, see “Add Custom Comments to Generated Code”.

## Customize Appearance of Identifiers

The ability to customize identifiers allows for easier integration of code generated by Embedded Coder with legacy code. It also simplifies compliance with company specific C coding standards.

- 1 Open model `throttlecntrl_codeappearance`.
- 2 Generate code and examine the identifiers in the generated file `throttlecntrl_codeappearance.c`.
- 3 Open the **Code Generation > Symbols** pane of the Configuration Parameters dialog box and explore the available options. For token and macro details, see the Help for a specific parameter.
- 4 Change the setting of the **Local block output variables** parameter to `OutVar_$$M`.
- 5 Generate code and examine the file `throttlecntrl_codeappearance.c`. Specifically, compare the following before and after code fragments:

Before

```
rtb_Sum3 = throttlecntrl_configert_U.pos_rqst -  
    throttlecntrl_configert_U.fbk_1;  
.  
.  
.  
rtb_Sum3 = throttlecntrl_configert_U.pos_rqst -  
    throttlecntrl_configert_U.fbk_2;
```

After

```
OutVar_Sum3 = throttlecntrl_codeappearance_U.pos_rqst -  
    throttlecntrl_codeappearance_U.fbk_1;  
.  
.  
.  
OutVar_Sum3 = throttlecntrl_codeappearance_U.pos_rqst -
```

```
throttlecntl_codeappearance_U.fbk_2;
```

- 6 Close the code and model files.

For more information, see “Identifier Format Control”.

## Customize Code Style

- 1 Open model `throttlecntl_codeappearance`.
- 2 Generate code and examine the style applied to code in the generated file `throttlecntl_codeappearance.c`.
- 3 Open the **Code Generation > Code Style** pane of the Configuration Parameters dialog box and explore the available options.
- 4 Change the setting of the **Parentheses level** parameter to Minimum (Rely on C/C++ operators for precedence).
- 5 Generate code and examine the file `throttlecntl_codeappearance.c`. Specifically, compare the following before and after code fragments:

Before

```
throttlecntl_configert_DWork.Discrete_Time_Integrator1_DSTAT = (((-0.03 *
    rt_Lookup((const real_T *)throttlecntl_configert_ConstP.pooled4, 9,
        rtb_Sum3, (const real_T *)throttlecntl_configert_ConstP.pooled5))
    * rtb_Sum3) * 0.001) +
throttlecntl_configert_DWork.Discrete_Time_Integrator1_DSTAT;
```

After

```
throttlecntl_codeappeara_DWork.Discrete_Time_Integrator1_DSTAT = -0.03 *
    rt_Lookup((const real_T *)throttlecntl_codeappear_ConstP.pooled4, 9,
        OutVar_Sum3, (const real_T *)
            throttlecntl_codeappear_ConstP.pooled5) * OutVar_Sum3 * 0.001 +
throttlecntl_codeappeara_DWork.Discrete_Time_Integrator1_DSTAT;
```

For more information, see “Control Code Style”

### Key Points

Control and customize the following aspects of generated code appearance to optimize the code, simplify maintenance, improve code readability, or comply with company code conventions and style:

- Customize aspects of generated code appearance to meet application requirements.
- You can document generated code specifying a level of code comments depending on the application objectives.
- You can customize identifiers in generated code, for example, to enhance readability or comply with company code guidelines or standards.
- Available code style customizations pertain to the parentheses level, operand order in expressions, condition expressions and patterns, and use of the `extern` keyword.

### Learn More

- “Add Custom Comments to Generated Code” and “Code Generation Pane: Comments”
- “Customize Generated Identifier Naming Rules” and “Code Generation Pane: Symbols”
- “Control Code Style” and “Code Generation Pane: Code Style”

# Configure Data Interface

## In this section...

- “About this Tutorial” on page 3-21
- “Create Data Objects for Named Data in Base Workspace” on page 3-22
- “Configure Data Objects” on page 3-22
- “Control Placement of Parameter and Constant Data in Generated Code” on page 3-23
- “Include Signal Data Objects in Generated Code” on page 3-25
- “Simulation and Data Typing” on page 3-26
- “View Data Objects in Generated Code” on page 3-27
- “Save Base Workspace Data” on page 3-28
- “Key Points” on page 3-28
- “Learn More” on page 3-28

## About this Tutorial

### Learning Objectives

- Configure the data interface for code generated from a model.
- Control the name, data type, and data storage class of signals and parameters in generated code.
- Control the placement of parameter data.

### Prerequisites

- Understanding of ways to represent and use data and signals in models.
- Familiarity with representing data constructs as data objects.
- Completed “Configure Data Interface” in the Simulink Coder documentation.

- Able to read C code.

### Required Files

- Model `rtwdemo_throttlecntl_dataplacement`
- Model `rtwdemo_throttlecntl_testharnessert`

## Create Data Objects for Named Data in Base Workspace

Use the Data Object Wizard to find constructs in the base workspace for which you can create data objects.

- 1 Open model `rtwdemo_throttlecntl_dataplacement`. Save a copy as `throttlecntl_dataplacement` in a writable location on your MATLAB path.
- 2 In the model window, select **Code > Data Objects > Data Object Wizard**. The Data Object Wizard dialog box opens.
- 3 In the Data Object Wizard dialog box, click **Find** to find candidate constructs. After a few minutes, constructs `fbk_1` and `pos_cmd_two` appear in the dialog box.
- 4 Click **Check All** to select both constructs.
- 5 Click **Apply Package** to apply the default Simulink package for the data objects.
- 6 Click **Create** to create the data objects. Constructs `fbk_1` and `pos_cmd_two` are removed from the dialog box.
- 7 Close the Data Object Wizard.
- 8 Open the Model Explorer, click **Base Workspace**. On the Contents pane, find the newly created objects `fbk_1` and `pos_cmd_two`.

## Configure Data Objects

- 1 In the Model Explorer, examine the contents of the base workspace.



- 2 Configure the `fbk_1` and `pos_cmd_two` signals with the following settings.

Signal	Data Type	Storage Class
<code>fbk_1</code>	double	ImportedExtern
<code>pos_cmd_two</code>	double	ExportedGlobal

- 3 Close the Model Explorer.
- 4 Save and close the model.

## Control Placement of Parameter and Constant Data in Generated Code

You can control which generated files contain model data definitions and declarations, for example, to adhere to company standards, by specifying files on the **Code Generation > Code Placement** pane of the Configuration Parameters dialog box.

For this tutorial, define and declare parameters in `eval_data.c` and `eval_data.h`. Separating the data declaration and assignment simplifies the integration of the code into the production environment.

- 1 Open your copy of the throttle controller model, `throttlecntrl_dataplacement`.
- 2 In the Configuration Parameters dialog box, open **Code Generation > Code Placement**.
- 3 Set **Data definition** to Data defined in a single separate source file and **Data declaration** to Data declared in a single separate header file.
- 4 Set **Data definition filename** and **Data declaration filename** to `eval_data.c` and `eval_data.h`, respectively.
- 5 Generate code for the model. When code generation is complete, `eval_data.c` and `eval_data.h` are in the model build folder.
- 6 Examine the data files.

### eval\_data.c

```
#include "rtwtypes.h"
#include "throttlecntrl_dataplacement_types.h"

/* Exported data definition */

/* Const memory section */
/* Definition for custom storage class: Const */
const real_T I_Gain = -0.03;
const real_T I_InErrMap[9] = { -1.0, -0.5, -0.25, -0.05, 0.0, 0.05, 0.25, 0.5,
    1.0 } ;

const real_T I_OutMap[9] = { 1.0, 0.75, 0.6, 0.0, 0.0, 0.0, 0.6, 0.75, 1.0 } ;

const real_T P_Gain = 0.74;
const real_T P_InErrMap[7] = { -1.0, -0.25, -0.01, 0.0, 0.01, 0.25, 1.0 } ;

const real_T P_OutMap[7] = { 1.0, 0.25, 0.0, 0.0, 0.0, 0.25, 1.0 } ;
```

### eval\_data.h

```
#ifndef RTW_HEADER_eval_data_h_
#define RTW_HEADER_eval_data_h_
#include "rtwtypes.h"
#include "throttlecntrl_dataplacement_types.h"

/* Const memory section */
/* Declaration for custom storage class: Const */
extern const real_T I_Gain;
extern const real_T I_InErrMap[9];
extern const real_T I_OutMap[9];
extern const real_T P_Gain;
extern const real_T P_InErrMap[7];
extern const real_T P_OutMap[7];

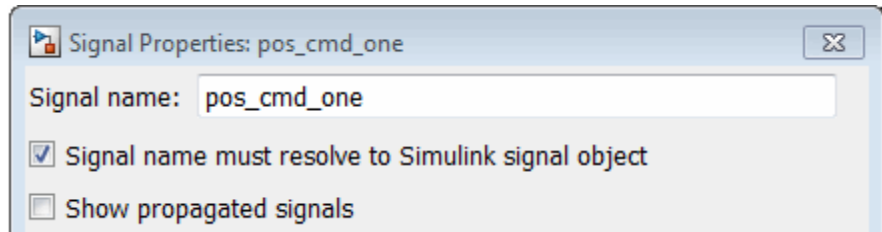
#endif /* RTW_HEADER_eval_data_h_ */
```

**7** Save and close the code files and model.

For more information, see “Manage Placement of Data Definitions and Declarations”.

## Include Signal Data Objects in Generated Code

- 1 Open your copy of the throttle controller model, `throttlectrl_dataplacement`.
- 2 In the Configuration Parameters dialog box, make sure that you select **Optimization > Signals and Parameters > Inline parameters**.
- 3 Enable signal data object `pos_cmd_one` to appear in the generated code.
  - a In the model window, right-click the `pos_cmd_one` signal line and select **Properties**. A Signal Properties dialog box opens.
  - b In the Signal Properties dialog box, make sure that you select **Signal name must resolve to a Simulink signal object**.



- 4 Enable signal object resolution for all signals in the model simultaneously. In the MATLAB Command Window, enter:

```
disableimplicitsignalresolution('throttlectrl_dataplacement')
```

Messaging in the MATLAB Command Window indicates that the following signal objects are resolved.

Signal...	Used By...
<code>pos_cmd_two</code>	<code>PI_ctrl_2/1</code>
<code>error_reset</code>	<code>Define_Throt_Param/Constant4/1</code>
<code>max_diff</code>	<code>Define_Throt_Param/Constant3/1</code>

Signal...	Used By...
fail_safe_pos	Define_Throt_Param/Constant/1
fbk_1	fbk_1/1

5 Save and close the model.

## Simulation and Data Typing

In the `throttlecntrl_dataplacement` model, all data types are set to `double`. Because Simulink software uses the `double` data type for simulation, do not expect changes in the model behavior when you run the generated code. You can verify this behavior by running the test harness.

Before you run your test harness, update it to include the `throttlecntrl_dataplacement` model.

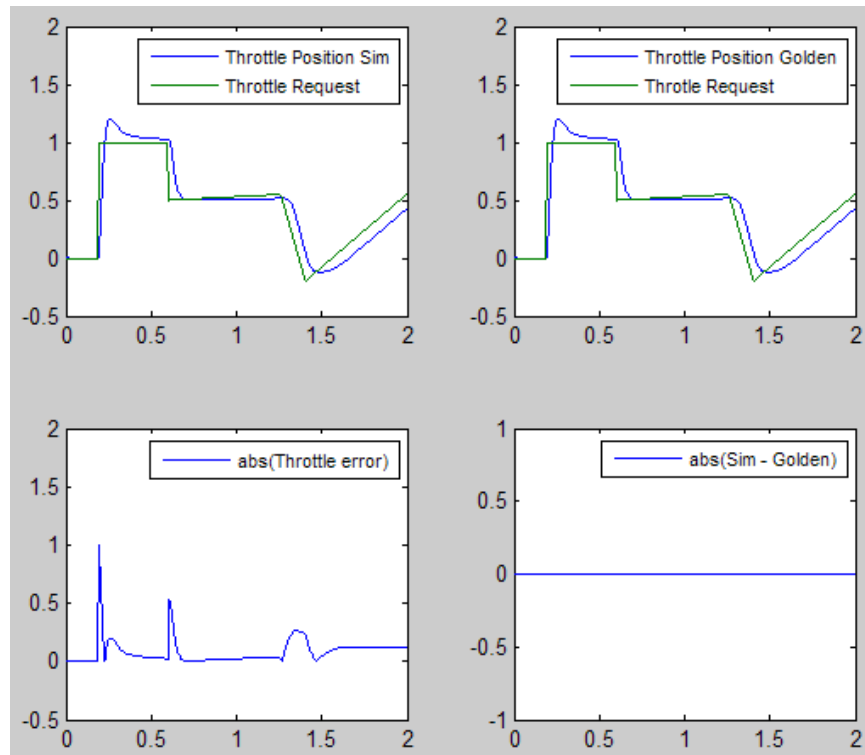
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**Note** The following procedure requires a Stateflow license.

---

- 1 Open model `throttlecntrl_dataplacement`.
- 2 Open model `rtwdemo_throttlecntrl_testharnessert`. Save a copy as `throttlecntrl_testharnessert`.
- 3 In the test harness model, right-click the `Unit_Under_Test Model` block and select **Block Parameters (ModelReference)**.
- 4 Set **Model name** to `throttlecntrl_dataplacement` and click **OK**.
- 5 Update the test harness model diagram (**Simulation > Update Diagram**).
- 6 Simulate the test harness.

The resulting plot shows that the difference between the golden and simulated versions of the model remains zero.



7 Save and close the test harness model.

## View Data Objects in Generated Code

- 1 Open your copy of the throttle controller model, `throttlecntrl_dataplacement`.
- 2 Generate code for the model.
- 3 Examine the code in the generated file, `throttlecntrl_dataplacement.c`.

The following statement shows a sampling of generated variables for the model before you converted the data to data objects.

```
rtb_Sum3 = my_throttlecntrl_dataplacement_U.pos_rqst...
- my_throttlecntrl_dataplacement_U.fbk_2;
```

After creating data objects for signals `pos_rqst` and `fbk_2`, the same line of generated code appears is:

```
rtb_Sum3 = *pos_rqst - fbk_2;
```

**4** Close the model.

### Save Base Workspace Data

In the base workspace, save the data that exists in the base workspace for future reference. In the MATLAB Command Window, enter `save`. Simulink places the data in the `matlab.mat` file in the model build folder.

### Key Points

- You can declare data in Simulink models and Stateflow charts by using data objects.
- You can manage (create, view, configure, and so on) base workspace data from the Model Explorer or in the MATLAB Command Window.
- The Data Object Wizard provides a quick way to create data objects for constructs such as signals, buses, and parameters.
- You must explicitly configure data objects to appear by name in generated code.
- Separation of the data from the model provides several benefits.

### Learn More

- “Import Data”
- “Data Representation ”
- “Introduction to Custom Storage Classes”
- “Manage Placement of Data Definitions and Declarations”

# Partition and Export Functions

**In this section...**

“About this Tutorial” on page 3-29

“Change Model Architecture to Control Execution Order” on page 3-30

“Control Function Location and File Placement in Generated Code” on page 3-32

“Use Mask to Pass Parameters into Library Subsystem” on page 3-35

“Generate Code for Full Model and Exported Functions” on page 3-37

“Change Execution Order and Simulation Results” on page 3-39

“Key Points” on page 3-41

“Learn More” on page 3-42

## About this Tutorial

### Learning Objectives

- Specify function and file names in generated code.
- Exert direct control over the execution order of model components.
- Identify parts of generated code used for integration.
- Generate code for atomic subsystems.
- Know what data you need to execute a generated function.

### Prerequisites

- Understand basic model architecture.
- Understand the difference between types of subsystems — see “Systems and Subsystems” in the Simulink documentation.
- Understand the purpose of function-call subsystems.
- Understand what reentrant code is.

- Familiarity with the Subsystem Parameters dialog box.
- Familiarity with the Mask Parameters dialog box.
- Familiarity with different ways to generate code for subsystems.
- Able to read C code.

### Required File

- Model `rtwdemo_throttlecntrl_funcpartition`
- Model `rtwdemo_throttlecntrl_testharnessert`

## Change Model Architecture to Control Execution Order

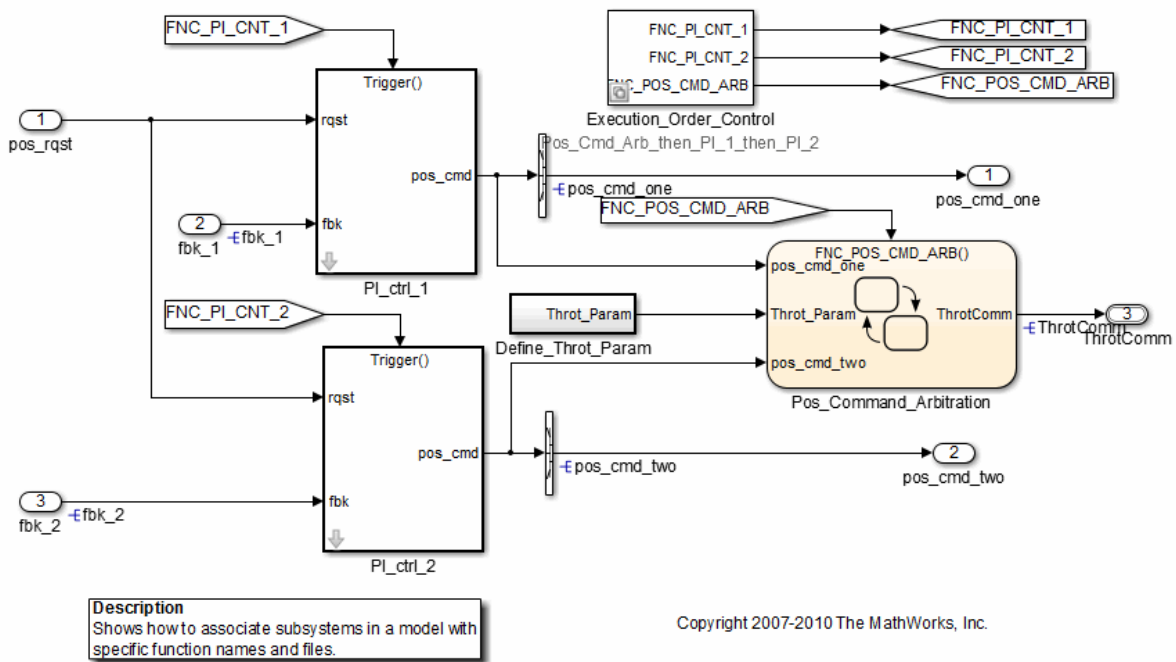
To match the behavior of a physical system, you might have to exert direct control over the execution order of model components. One way of controlling execution order is to use function-call subsystems and a Stateflow chart that models the calling functionality of a scheduler.

The example throttle controller model includes virtual subsystems. This tutorial shows you how to replace the virtual subsystems with function-call subsystems, and use them to control subsystem execution order.

- 1 Open model `rtwdemo_throttlecntrl_funcpartition`. Save a copy as `throttlecntrl_funcpartition` in a writable location on your MATLAB path.

This version of the throttle controller model includes three function-call subsystems and a subsystem consisting of a Stateflow chart, which controls execution order of the other subsystems.



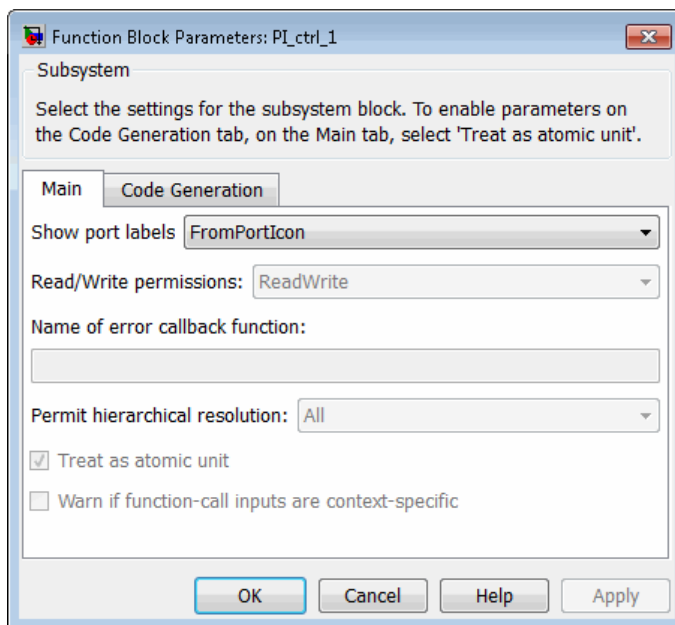


- 2 Examine the function-call subsystems PI\_ctrl\_1, PI\_ctrl\_2, and Pos\_Command\_Arbitration.
- 3 Examine the Stateflow chart subsystem Execution\_Order\_Control. This subsystem controls the execution order of the function-call subsystems. Later in the tutorial, you see how changing execution order can change simulation results.
- 4 Examine the new Signal Conversion blocks for output ports pos\_cmd\_one and pos\_cmd\_two of the PI controllers. The Signal copy setting for the **Output** block parameter makes it possible for the PI controller functions in the generated code to be reentrant.
- 5 Close the model.

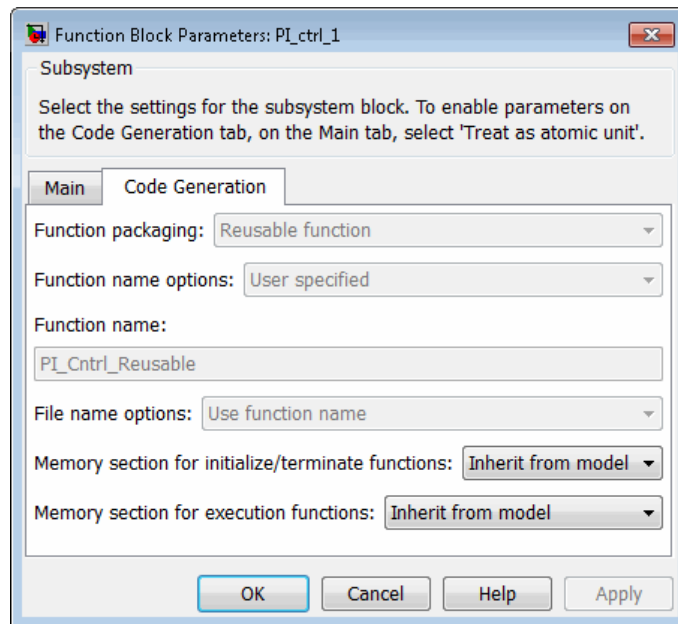
## Control Function Location and File Placement in Generated Code

So far, the code generator has produced a `model_step` function, which contains all control algorithm code for the throttle controller model. However, many applications require a greater level of control over the location of functions in the generated code. By using atomic subsystems, you can instruct the code generator to partition algorithm code across multiple functions. You specify the partitioning by modifying parameters in the Subsystem Parameters dialog box for each subsystem.

- 1 Open your copy of the throttle controller model, `throttlectrl_funcpartition`.
- 2 Open the Block Parameters dialog box for subsystems `PI_ctrl1_1` and `PI_ctrl1_2`. Examine the parameter settings.
  - a Right-click the subsystem and select **Block Parameters (Subsystem)**. The Function Block Parameters dialog box opens.



- b** On the **Main** tab, **Treat as atomic unit** is selected. This parameter is automatically selected and unavailable for atomic subsystems. When set, this parameter causes Simulink software to treat block methods associated with a subsystem as a unit when determining execution order. The parameter provides a way to group functional aspects of a model at the execution level. This parameter enables parameters on the **Code Generation** tab.
- c** Click the **Code Generation** tab.



- d** Note the following parameter settings:

Parameter	Rationale for Setting
<b>Function packaging</b>	Reusable function causes the code generator to produce reentrant code for the subsystem. Reentrant code is a reusable programming routine that multiple programs can use simultaneously. Operating systems and other system software that use multithreading to handle concurrent events use reentrant code. Reentrant code does not maintain state data. No persistent variables are in the function. Calling programs maintain state variables and pass them into the function. Any number of users or processes can share one copy of a reentrant routine
<b>Function name options</b>	User Specified enables you to specify a unique name for the generated function.
<b>Function name</b>	Enables you to name the function that the code generator produces for a subsystem. In this case, the code generator names the reusable function PI_Cntrl_Reusable.
<b>File name options</b>	Use function name causes the code generator to place the generated function in a separate file and name it with the same name as the generated function. In this case, the code generator places the function in the model build folder in the file the PI_Cntrl_Reusable.c.

- 3 Open the Subsystem Parameters dialog box for subsystem Pos\_Command\_Arbitration and examine the parameter settings. **Treat as atomic unit** on the **Main** tab is already selected. The following table provides the rationale for the parameter settings on the **Code Generation** tab.

Parameter	Rationale for Setting
<b>Function packaging</b>	Nonreusable function causes the code generator to produce a separate function that is not reentrant and has no arguments.
<b>Function name options</b>	Auto assigns the generated function a unique name using the default convention <i>model_subsystem()</i> . <i>model</i> is the name of the model and <i>subsystem</i> is the name of the subsystem. In this case, the function name is <code>throttlectrl_funcpartition_Pos_Command_Arbitration</code> .
<b>File name options</b>	Auto causes the code generator to place the function code in the <code>throttlectrl_funcpartition.c</code> file.

**4** Open the Subsystem Parameters dialog box for subsystem `Execution_Order_Control` and examine the parameter settings. For this subsystem, the **Treat as atomic unit** parameter is not set, restricting **Function packaging** to Nonreusable function only.

**5** Close the model.

For more information, see [Subsystem](#).

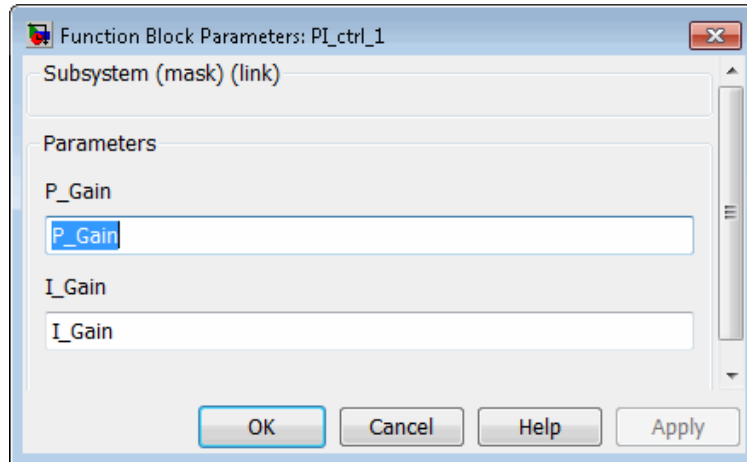
## Use Mask to Pass Parameters into Library Subsystem

Subsystem *masks* enable Simulink software to define subsystem parameters outside the scope of a library block. By changing the parameter value at the top of the library, you can reuse the same library with multiple sets of parameters within the same model.

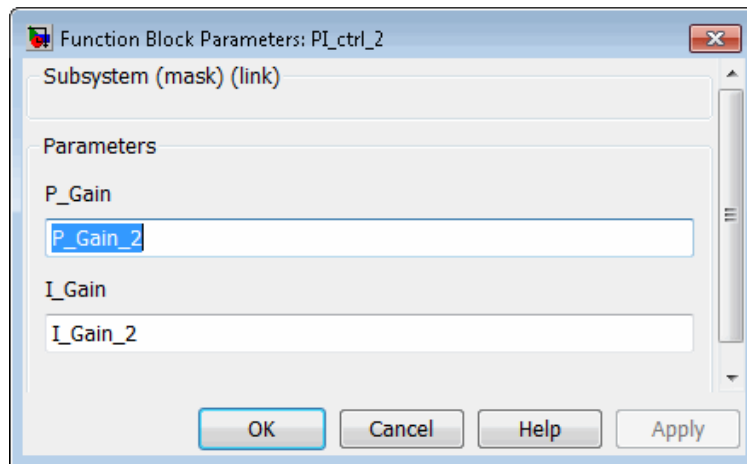
When a subsystem is reusable and has a mask, the generated code passes the masked parameters into the reentrant code as arguments. Code generation software fully supports the use of data objects in masks. The data objects are used in the generated code.

Examine the masks for subsystems `PI_ctrl_1` and `PI_ctrl_2`.

- 1 Open your copy of the throttle controller model, `throttlectrl_funcpartition`.
- 2 Open the Mask Parameters dialog box for subsystem `PI_ctrl1` by double-clicking the subsystem. The dialog box opens, showing data objects for gain parameters `P_gain` and `I_gain`.



- 3 Open the Mask Parameters dialog box for subsystem `PI_ctrl1_2`. For this subsystem, Simulink creates two new data objects, `P_Gain_2` and `I_Gain_2`.



- 4 Close the Mask Parameters dialog boxes and the model.

## Generate Code for Full Model and Exported Functions

The code generator can build code at the system (full model) and subsystem levels. Compare the files generated for the full model build with files generated for exported functions.

- 1 Open your copy of the throttle controller model, `throttlectrl_funcpartition`.
- 2 Generate code for the model.
- 3 Export a function for the `PI_ctrl_1` subsystem.
  - a In the model window, right-click `PI_ctrl_1` and select **Code Generation > Export Functions**. The **Build code for Subsystem** dialog box opens.
  - b In the **Build code for Subsystem** dialog box, click **Build**. The code generator produces a complete set of code files for the subsystem and places them in the build folder `PI_ctrl_1_ert_rtw`.
- 4 If you have a Stateflow license, export a function for the `Pos_Command_Arbitration` subsystem. The code generator produces a complete set of code files for the subsystem and places them in the build folder `Pos_Command_Arbitration_ert_rtw`.
- 5 Examine the generated code listed in the following table by locating and opening the files in the respective build folders.

File	Full Build	PI_ctrl_1	Pos_Command - Arbitration (requires Stateflow license)
<code>throttlectrl_funcpartition.c</code>	Yes Step function	No	No
<code>PI_ctrl_1.c</code>	No	Yes Trigger function	No

File	Full Build	PI_ctrl_1	Pos_Command - Arbitration (requires Stateflow license)
Pos_Command_Arbitration.c (requires Stateflow license)	No	No	Yes Initialization and Function
PI_Ctrl_Reusable.c	Yes Called by main	Yes Called by PI_ctrl_1	No
ert_main.c	Yes	Yes	Yes
eval_data.c	Yes*	Yes*	No Eval data not used in diagram

\* The content of `eval_data.c` differs between the full model and export function builds. The full model build includes all parameters that the model uses while the export function contains only variables that the subsystem uses.

6 Close all dialog boxes and the model.

### Examine Masked Data in Generated Code

1 Open `throttlectrl_funcpartition.c`.

2 Search for `PI_Cntrl_Reusable`. The function call shows how the code generator passes data objects (`P_Gain` and `I_Gain`) from the subsystem masks into the reentrant code.

```
PI_Cntrl_Reusable(pos_rqst, fbk_1, &throttlectrl_funcpartiti_DWork_DWork->PI_ctrl_1, I_Gain, P_Gain);
```

3 Search for `PI_Cntrl_Reusable` again. The second function call passes data objects from the mask for subsystem `PI_ctrl_2`.

```
PI_Cntrl_Reusable(pos_rqst, fbk_2, &throttlectrl_funcpartiti_DWork->PI_ctrl_2,
```



```
I_Gain_2, P_Gain_2);
```

4 Close the C code file.

## Change Execution Order and Simulation Results

Without explicit control, subsystems in model `throttlecntrl_funcpartition` execute in the following order:

- 1 `PI_ctrl_1`
- 2 `PI_ctrl_2`
- 3 `Pos_Cmd_Arbitration`

You can use the test harness to see how the execution order can change the simulation results. The `Execution_Order_Control` subsystem is set up so that you can switch between two configurations, which change the execution order of the other subsystems in the model.

---

**Note** The following procedure requires a Stateflow license.

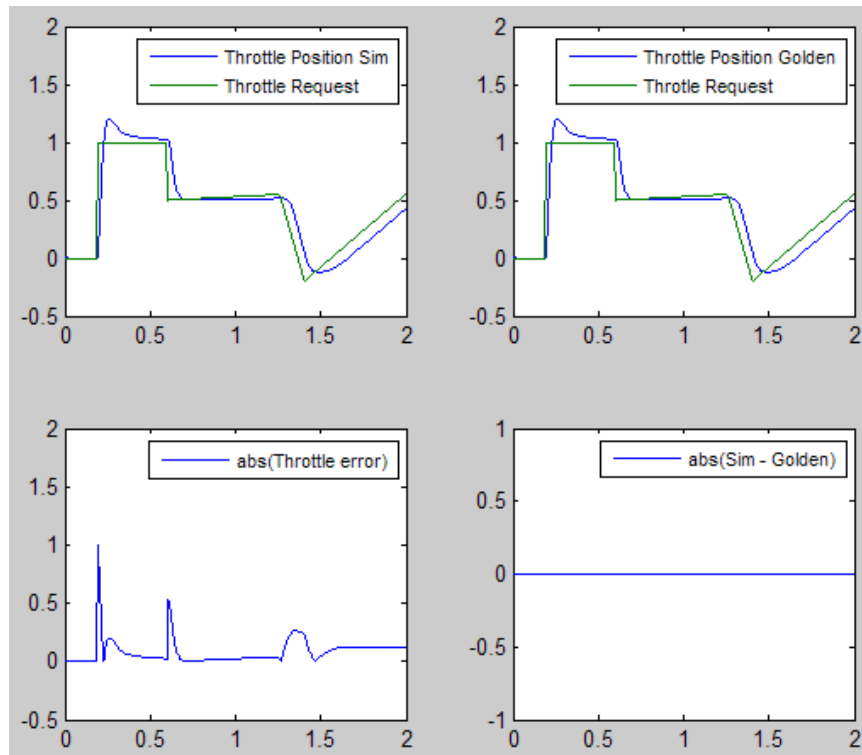
---

Change the execution order.

- 1 Open your copy of the throttle controller model, `throttlecntrl_funcpartition`.
- 2 Right-click the `Execution_Order_Control` subsystem. Select **Block Choice > PI\_1\_then\_PI\_2\_then\_Pos\_Cmd\_Arb** to set the subsystem execution order to `PI_ctrl_1`, `PI_ctrl_2`, then `Pos_cmd_Arbitration`.
- 3 Save the model.
- 4 Open the test harness model, `throttlecntrl_testharnessert`.
- 5 Set up the test harness to use model `throttlecntrl_funcpartition` as the unit under test.
  - a Right-click the `Unit_Under_Test Model` block and select **Model Reference Parameters**.

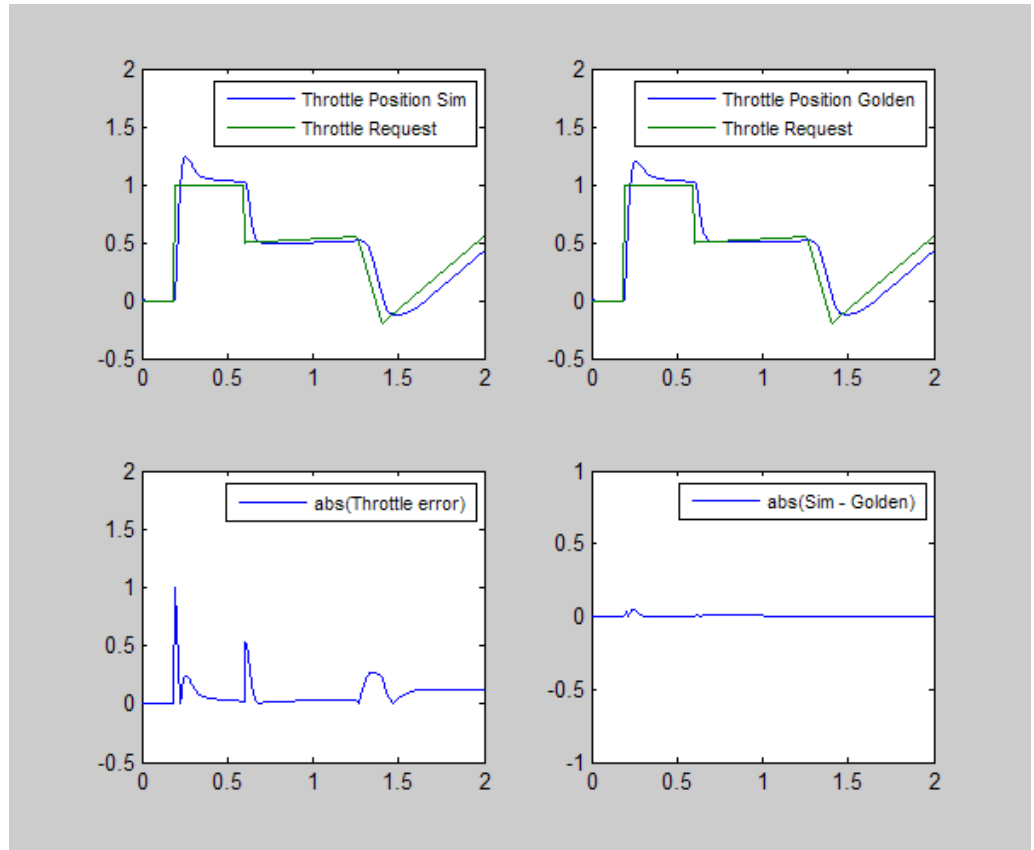
- b** Set **Model name** to `throttlecntrl_funcpartition` and click **OK**.
  - c** Update the model diagram.
- 6** Run the test harness.

The resulting plot shows that the difference between the golden and simulated versions of the model remains zero.



- 7** In the model `throttlecntrl_funcpartition`, change the execution order to `Pos_cmd_Arbitration_then_PI_1_then_PI_2`, update the model diagram, and save the model.
- 8** Run the test harness again.

A slight variation exists in the output results depending on the order of execution. The difference is most noticeable when the desired input changes.



9 Close the throttle controller and test harness models.

## Key Points

- One way of controlling execution order of subsystems during simulation is to use function-call subsystems and a Stateflow chart that models the calling functionality of a scheduler.

- For atomic subsystems, you can instruct the code generator to partition algorithm code across multiple functions.
- When partitioning code across multiple functions, you can specify the name of the function for each subsystem and the name of the separate file for the code with parameters in the Subsystem Parameters dialog box.
- When a subsystem is reusable and has a mask, the generated code passes the masked parameters into the reentrant code as arguments.
- The code generator can build code at the system (full model) and subsystem levels.
- At the subsystem level, the code generator produces a full set of generated files in a separate build folder.
- You can change the execution of a model by using a subsystem containing a Stateflow chart that models the calling functionality of a scheduler and changing the setting of the **Block Choice** option on the subsystem's context menu.

### Learn More

- “Modeling”
- “Insert S-Function Code”
- “Export Function-Call Subsystems”
- “Function Prototype Control”
- “Masking”

# Integrate Generated Code into External Environment

**In this section...**

“About this Tutorial” on page 3-43

“Relocate Code to Another Development Environment” on page 3-44

“Integrate Generated Code into Existing System” on page 3-45

“Set Up Main Function” on page 3-45

“Match System Interfaces” on page 3-47

“Build Project in Eclipse Environment” on page 3-50

“Key Points” on page 3-51

“Learn More” on page 3-51

## About this Tutorial

### Learning Objectives

- Collect and relocate files to build an executable outside of the Simulink environment.
- Set up generated code to interface with external variables and functions.
- Build a full system that includes your generated code.

### Prerequisites

- Access to installed versions of the Eclipse Integrated Development Environment (IDE) and the Cygwin Debugger. However, required integration tasks shown in the tutorial are common to all integration environments. For information on how to install the Eclipse IDE and Cygwin Debugger, see Appendix A, “Installing and Using IDE”
- Able to read C code.
- Familiarity with debugging tools and capabilities.

## Required Files

- Model `rtwdemo_throttlecntrl_externenv`
- Files in `matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/externenv_files`, where `matlabroot` is your MATLAB installation folder

## Relocate Code to Another Development Environment

Generated code depends on static support files that MathWorks provides. If you need to relocate the static and generated code files for a model to another development environment, such as a dedicated build system, use the Simulink Coder pack-and-go utility (`packNGo`). This utility finds the files for building an executable image, including external files you define in the **Code Generation > Custom Code** pane of the Configuration Parameters dialog box, and packages them in a zip file.

- 1 Open model `rtwdemo_throttlecntrl_externenv`. Save a copy to `throttlecntrl_externenv` in a writable location on your MATLAB path. Proceed through the tutorial from this location.

- 2 Generate code for the model.

After code generation, the model is configured to run `packNGo`.

- 3 In your working folder, find and examine the contents of the generated file `throttlecntrl_externenv.zip`.

The number of files in the zip file depends on the version of Embedded Coder software that you are running and the configuration of the model. The compiler does not require all files in the zip file. The compiled executable size (RAM/ROM) is dependent on the link process. You must configure the linker to include only required object files.

To generate the zip file manually, in the MATLAB Command Window:

- 1 Load the `buildInfo.mat` file, located in the build folder for the model.
- 2 Enter the command `packNGo(buildInfo)`.

For more information about using the `packNGo` utility, see “Relocate Code to Another Development Environment” in the Simulink documentation.

## Integrate Generated Code into Existing System

A full embedded controls system has multiple components, both hardware and software. Control algorithms are just one type of component. The other standard types of components include:

- An operating system (OS)
- A scheduling layer
- Physical hardware I/O
- Low-level hardware device drivers

In general, code is not generated for any of these components. Instead, you develop interfaces that connect the components. MathWorks provides hardware interface block libraries for many common embedded controllers. For details, see the block libraries under Embedded Targets.

## Set Up Main Function

For this tutorial, you modify a supplied `main` function to build a full system. The `main` function performs basic actions to exercise the code for a simple system. It is *not* an example of an actual application `main` function.

- 1 Copy files for the example `main` function to your working folder. The files are in `matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/externenv_files`. `matlabroot` represents the name of your MATLAB installation folder.
- 2 Open and examine the code in the file `example_main.c`.

---

**Note** For the `example_main.c` file, name your copy of the model file `rtdemo_throttlecntrl_externenv` as `throttlecntrl_externenv`.

---

```
#include <stdio.h>                /* This ert_main.c example uses printf/fflush */
#include "throttlecntrl_externenv.h" /* Model's header file */
```

```
#include "rtwtypes.h"                /* MathWorks types */
#include "throttlecntrl_externenv_private.h" /* Local data for PCG Eval */
#include "defineImportedData.h"       /* The inputs to the system */

/* Observable signals */
static BlockIO_throttlecntrl_externenv throttlecntrl_externenv_B;
/* Observable states */
static D_Work_throttlecntrl_externenv throttlecntrl_externenv_DWork;

real_T pos_cmd_one;                 /* '<Root>/Signal Conversion1' */
real_T pos_cmd_two;                 /* '<Root>/Signal Conversion2' */
ThrottleCommands ThrotComm;         /* '<Root>/Pos_Command_Arbitration' */
ThrottleParams Throt_Param;         /* '<S1>/Bus Creator' */

int simulationLoop = 0;

int_T main(void)
{
    /* Initialize model */
    rt_Pos_Command_Arbitration_Init(); /* Set up the data structures for chart*/
    throttle_cnt_Define_Throt_Param(); /* SubSystem: '<Root>/Define_Throt_Param' */
    defineImportData();                /* Defines the memory and values of inputs */

    do /* This is the "Schedule" loop.
        Functions would be called based on a scheduling algorithm */
    {
        /* HARDWARE I/O */

        /* Call control algorithms */
        PI_Cntrl_Reusable((*pos_rqst),fbk_1,&throttlecntrl_externenv_B.PI_ctrl_1,
                          &throttlecntrl_externenv_DWork.PI_ctrl_1);
        PI_Cntrl_Reusable((*pos_rqst),fbk_2,&throttlecntrl_externenv_B.PI_ctrl_2,
                          &throttlecntrl_externenv_DWork.PI_ctrl_2);
        pos_cmd_one = throttlecntrl_externenv_B.PI_ctrl_1.Saturation1;
        pos_cmd_two = throttlecntrl_externenv_B.PI_ctrl_2.Saturation1;

        throttle_Pos_Command_Arbitration(pos_cmd_one, &Throt_Param, pos_cmd_two,
                                          &throttlecntrl_externenv_B.sf_Pos_Command_Arbitration);
    }
}
```



```
        simulationLoop++;  
    } while (simulationLoop < 2);  
    return 0;  
}
```

Identify areas of the code that perform each of the following functions:

- Defines function interfaces (function prototypes)
- Includes required files for data definition
- Defines extern data
- Initializes data
- Calls simulated hardware
- Calls algorithmic functions

### 3 Close `example_main.c`.

The order of execution of functions in `example_main.c` matches the order in which the test harness model and `throttlectrl_externenv.h` call the subsystems. If you change the order of execution in `example_main.c`, results from the executable image differ from simulation results.

## Match System Interfaces

Integration requires matching the *data* and *function* interfaces of the generated code and the existing system code. In this example, the `example_main.c` file defines the data with `#include` statements and calls the functions from the generated code.

### 1 Specify input data.

The system has three input signals: `pos_rqst`, `fbk_1`, and `fbk_2`. The two feedback signals are imported externs (`ImportedExtern`) and the position signal is an imported extern pointer (`ImportedExternPointer`). Because of how the signals are defined, the code generator does not create variables

for them. Instead, the signal variables are defined in a file that is external to the MATLAB environment.

- a Open your copy of the file `defineImportedData.c`.

```
/* Define imported data */
#include "rtwtypes.h"
real_T fbk_1;
real_T fbk_2;
real_T dummy_pos_value = 10.0;
real_T *pos_rqst;
void defineImportData(void)
{
    pos_rqst = &dummy_pos_value;
}
```

This file contains code for a simple C stub that defines the signal variables. The generated code has access to the data from the extern definitions in your generated `throttlecntrl_externenv_Private.h` file. In a real system, the data comes from other software components or from hardware devices.

- b Close `defineImportedData.c`.
- c In your build folder, open `throttlecntrl_externenv_Private.h`.
- d Find and examine the following extern definitions.

```
/* Imported (extern) block signals */
extern real_T fbk_1;          /* '<Root>/fbk_1' */
extern real_T fbk_2;          /* '<Root>/fbk_2' */

/* Imported (extern) pointer block signals */
extern real_T *pos_rqst;      /* '<Root>/pos_rqst' */
```

- e Close `throttlecntrl_externenv_Private.h`.

## 2 Specify output data.

You do not have to do anything with the output data. However, you can access the data in your generated `throttlecntrl_externenv.h` file.

- a In your build folder, open `throttlecntrl_externenv.h`

- b** Examine the contents of the file.
- c** Close `throttlecntrl_externenv.h`.

“Verify Generated Code” on page 3-52 shows how to save the output data to a log file.

### 3 Identify additional data.

The code generator creates several data elements that you do not need to access to complete this tutorial. Such data elements include:

- Block state values (integrator, transfer functions)
- Local parameters
- Time

For this tutorial, the `throttlecntrl_externenv.h` file declares this data.

- a** In your build folder, open `throttlecntrl_externenv.h`
- b** Search the file for the data listed in the following table. The table lists the most common data structures. Depending on the configuration of the model, some or all of these structures are in the generated code.

<b>Data Type</b>	<b>Data Name</b>	<b>Data Purpose</b>
Constants	<code>throttlecntrl_externenv_cP</code>	Constant parameters
Constants	<code>throttlecntrl_externenv_cB</code>	Constant block I/O
Output	<code>throttlecntrl_externenv_U</code>	Root and atomic subsystem input
Output	<code>throttlecntrl_externenv_Y</code>	Root and atomic subsystem output
Internal data	<code>throttlecntrl_externenv_B</code>	Value of block output
Internal data	<code>throttlecntrl_externenv_D</code>	State information vectors
Internal data	<code>throttlecntrl_externenv_M</code>	Time and other system level data
Internal data	<code>throttlecntrl_externenv_Zero</code>	Zero-crossings
Parameters	<code>throttlecntrl_externenv_P</code>	Parameters

- c** Close `throttlecntrl_externenv.h`.

### 4 Match the function-call interface.

By default, the code generator creates functions that have a `void Func(void)` interface. If you configure the model or an atomic subsystem as reentrant code, the code generator creates a more complex function prototype.

- a** Open your copy of `example_main.c`.
- b** The `example_main` function is configured to call the functions.

```
throttlecntrl_externenv_B.sf_Pos_Command_Arbitration);
    ((*pos_rqst),fbk_1,&throttlecntrl_externenv_B.PI_ctrl_1,
    &throttlecntrl_externenv_DWork.PI_ctrl_1);
PI_Cntrl_Reusable((*pos_rqst),fbk_2,&throttlecntrl_externenv_B.PI_ctrl_2,
    &throttlecntrl_externenv_DWork.PI_ctrl_2);
pos_cmd_one = throttlecntrl_externenv_B.PI_ctrl_1.Saturation1;
pos_cmd_two = throttlecntrl_externenv_B.PI_ctrl_2.Saturation1;

throttlePos_Command_Arbitration(pos_cmd_one, &Throt_Param, pos_cmd_two,
    &throttlecntrl_externenv_B.sf_Pos_Command_Arbitration);
```

Calls to the `PI_Cntrl_Reusable` function use a mixture of user-defined variables and default data structures. The build process defines data structures in `throttlecntrl_externenv.h`. The preceding code fragment also shows how the data structures map to user-defined variables.

## Build Project in Eclipse Environment

This tutorial uses the Eclipse IDE to build the embedded system.

- 1** Create a build folder on your C drive. Name the folder such that the path contains no spaces (for example, `EclipseProjects/throttlecntrl/externenv`). For this tutorial and “Verify Generated Code” on page 3-52, you use the Cygwin Debugger, which requires that your build folder be on your C drive and the folder path not include spaces.

---

**Note** If you have not generated code for the model, or the zip file does not exist, complete the steps in “Relocate Code to Another Development Environment” on page 3-44 before continuing to the next step.

---

- 2 Unzip the file `throttlecntrl_externenv.zip` into the build folder you just created.
- 3 Delete the files `ert_main.c` and `throttlecntrl_externenv.c`. Then, add `example_main.c` that you examined in “Set Up Main Function” on page 3-45.
- 4 Use the Eclipse Integrated Development Environment (IDE) and Cygwin Debugger to step through and evaluate the execution behavior of the generated C code. For instructions on installing the IDE, creating a new project, and configuring the debugger, see Appendix A, “Installing and Using IDE”.
- 5 Close model `throttlecntrl_externenv`.

## Key Points

- You can find and package all files you need to build an executable image in an alternative build environment by using the Simulink Coder pack-and-go utility.
- A main function performs actions to exercise the code for a system.
- Integration of system components requires matching data and function interfaces of generated code and existing system code.
- Depending on the system, you might need to consider input data, output data, and other data generated in the generated `model.h` file.

## Learn More

- “Relocate Code to Another Development Environment”
- “Data Exchange”
- “Real-Time and Embedded Systems”
- “Compiler or IDE Selection and Configuration”

## Verify Generated Code

In this section...
“About this Tutorial” on page 3-52
“Methods for Verifying Generated Code” on page 3-53
“Reuse Test Data By Importing and Exporting Test Vectors” on page 3-54
“Verify Behavior of Model with Software-in-the-Loop Testing” on page 3-55
“Verify System Behavior By Importing and Exporting Test Vectors” on page 3-58
“Test with Processor-in-the-Loop Testing” on page 3-60
“Key Points” on page 3-61
“Learn More” on page 3-61

### About this Tutorial

#### Learning Objectives

- Identify methods available for testing generated code.
- Test generated code in the Simulink environment.
- Test generated code outside of the Simulink environment.

#### Prerequisites

- Access to installed versions of the Eclipse Integrated Development Environment (IDE) and the Cygwin Debugger. However, required integration tasks shown in the tutorial are common to all integration environments. For information on how to install the Eclipse IDE and Cygwin Debugger, see Appendix A, “Installing and Using IDE”
- Able to read C code.
- Familiarity with debugging tools and capabilities.

## Required Files

- Model `rtwdemo_throttlecntrl_testcode`
- Model `rtwdemo_throttlecntrl_testharnessSIL`
- Files in `matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/testcode_files`, where `matlabroot` is your MATLAB installation folder

## Methods for Verifying Generated Code

Simulink software supports multiple methods for verifying the behavior of code generated for a system.

Test Method	What the Method Does	Advantages	Disadvantages
Microsoft Windows run-time executable	Generates a Windows executable and runs the executable from the command prompt	Easy to create Can use C debugger to evaluate code	Emulates only part of the target hardware
Software-in-the-loop (SIL) testing	Uses an S-function wrapper to include the generated code in a Simulink model	Easy to create Allows you to reuse the Simulink test environment Can use C debugger to evaluate code	Emulates only part of the target hardware
Processor-in-the-loop (PIL) testing	Downloads code to a target processor and communicates with it from Simulink; see	Allows you to reuse the Simulink test environment	Requires additional steps to set up test environment

Test Method	What the Method Does	Advantages	Disadvantages
	“How SIL and PIL Simulations Work”	Can use C debugger with the simulation Uses actual processor	
On-target rapid prototyping	Runs generated code on the target processor as part of the full system	Can determine actual hardware constraints Allows testing of component within the full system Processor runs in real time	Requires hardware Requires additional steps to set up test environment

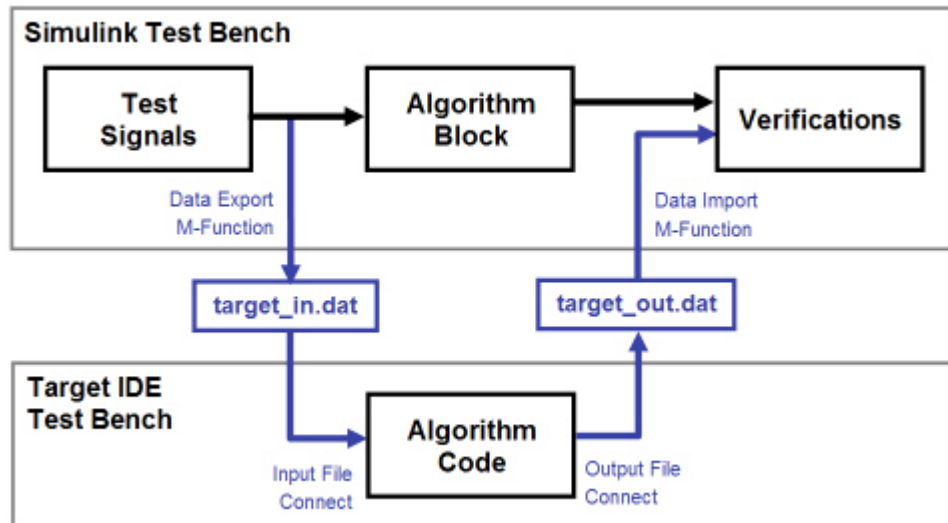
### Reuse Test Data By Importing and Exporting Test Vectors

When a unit under test is in the Simulink environment, you can reuse test data inside and outside of the Simulink environment.

- 1** Save the Simulink data into a file.
- 2** Format the data in a way that is accessible to the system code.
- 3** Read the data file as part of the system code procedures.

You can also reuse data from an external environment, such as an interactive development environment (IDE) for a specific target, in the Simulink test environment. To do so, you must save the data in a format that MATLAB software can read.



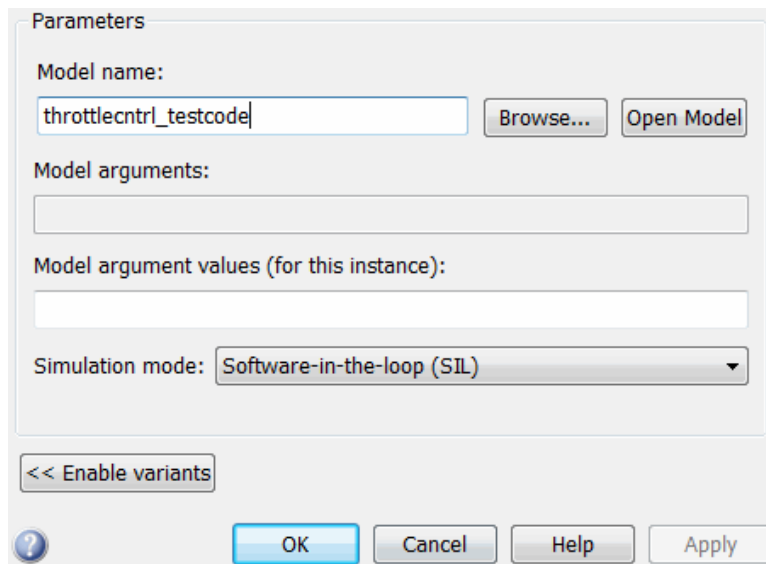


## Verify Behavior of Model with Software-in-the-Loop Testing

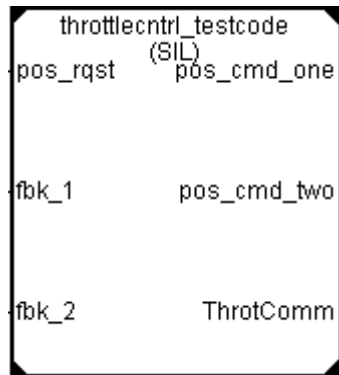
You can automatically generate code from a Model block, wrap the code in an S-Function, and bring the S-Function into another model for software-in-the-loop testing.

- 1 Configure the model you want to test.
  - a Open model `rtwdemo_throttlecntrl_testcode`. Save a copy to `throttlecntrl_testcode` in a writable location on your MATLAB path. Proceed through the tutorial from this location.
  - b Open the Configuration Parameters dialog box. Set **Hardware Implementation > Device vendor** to Generic and **Hardware Implementation > Device type** to 32-bit x86 compatible.
  - c Click **OK** to apply the changes. Close the dialog box.
- 2 Make sure that you can build an executable for `throttlecntrl_testcode`.
- 3 Configure the test harness model.

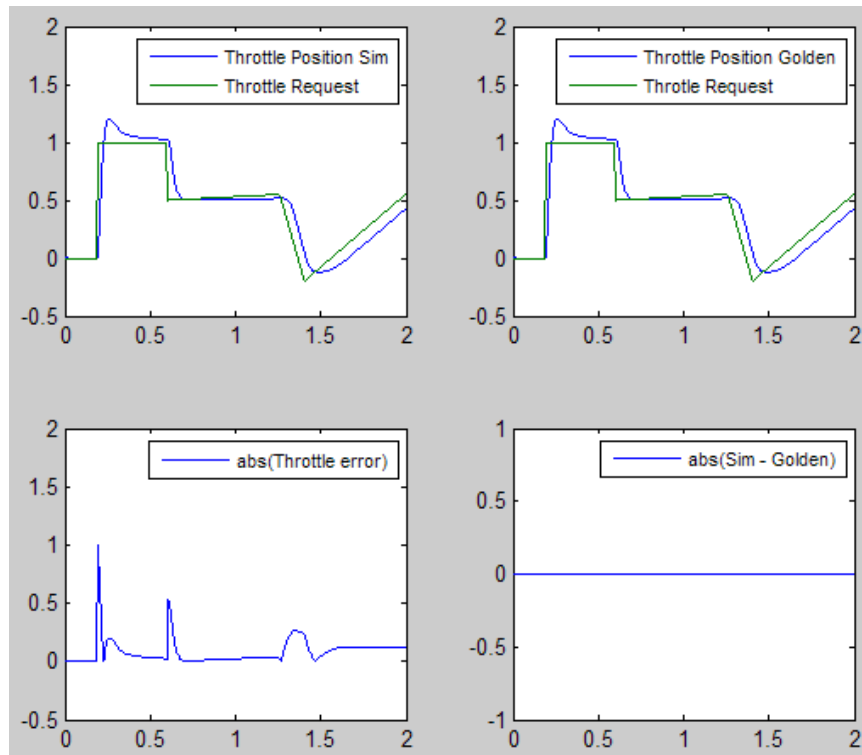
- a Open model `rtwdemo_throttlecntrl_testharnessSIL`. Save a copy to `throttlecntrl_testharnessSIL` in a location on your MATLAB path. The test harness uses a Model block to access the model to verify with software-in-the-loop (SIL) testing.
- b Right-click the `throttlecntrl_testcode` Model block and select **Model Reference Parameters**.
- c Set **Model name** to `throttlecntrl_testcode`.
- d Set **Simulation mode** to **Software-in-the-loop (SIL)** and click **OK**.



After you configure the Model block for SIL verification, the block includes a (SIL) tag, as the following figure shows:



- e Update the test harness model diagram (**Simulation > Update Diagram**).
- 4 Run the test harness. As the following plot shows, the results from running the generated code are the same as the simulation results.



## Verify System Behavior By Importing and Exporting Test Vectors

### About the example\_main.c

This example extends the example in “Integrate Generated Code into External Environment” on page 3-43. In this case, `example_main.c` simulates hardware I/O.

Open `matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/verification_files/example_main.c`.

This version of `example_main.c` has the following order of execution:

- Initialize data (one time)

```
while < endTime
```

- Read simulated hardware input
  - PI\_cntrl\_1
  - PI\_cntrl\_2
  - Pos\_Command\_Arbitration
  - Write simulated hardware output
- ```
end while
```

The `example_main.c` uses two functions, `plant` and `hardwareInputs`.

| File Name        | Function Signature        | Comments                                                                                                                                      |
|------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Plant.c          | void Plant(void)          | Code generated from the plant section of the test harness. Simulates the throttle body response to throttle commands.                         |
| HardwareInputs.c | void hardwareInputs(void) | Provides the <code>pos_req</code> signal and adds noise from the <code>Input_Signal_Scaling</code> subsystems into the plant feedback signal. |

A handwritten function, `WriteDataForEval.c`, logs data. When the test is complete, the function executes and writes test data to the file, `ThrottleCtrl_ExternSimData.m`. You can load this file into the MATLAB environment and compare the data to simulation data.

## Import and Export Test Vectors Using the Eclipse Environment

This tutorial uses the Eclipse Integrated Development Environment (IDE) debugger to build an embedded system.

- 1 Open your copy of the throttle controller model, `throttlecntrl_testcode`.

- 2 Add the additional files required to build an executable. In the Configuration Parameter dialog box, add the following paths for **Code Generation > Custom Code > Include list of additional > Include directories**:

```
"$matlabroot$\toolbox\rtw\rtwdemos\EmbeddedCoderOverview\  
"$matlabroot$\toolbox\rtw\rtwdemos\EmbeddedCoderOverview\verification_files\"
```

- 3 Make sure the model configuration parameter **Code Generation > Verification > Create block** is set to None.
- 4 Build the model.
- 5 Create a build folder on your C drive. Name the folder such that the path contains no spaces (for example, EclipseProjects/throttlecntrl/testcode). For this tutorial, you use the Cygwin Debugger, which requires that your build folder be on your C drive and that the folder path not include spaces.
- 6 Unzip the throttlecntrl\_testcode.zip file, in your working folder, into the build folder that you just created.
- 7 Delete the ert\_main.c and throttlecntrl\_testcode.c files. Then, add example\_main.c that you examined in “Set Up Main Function” on page 3-45.
- 8 Run the control code in Eclipse to generate the eclipseData.m file. This is the file that writeDataForEval.c generates.  
  
Consult “Integrating and Testing Code with Eclipse IDE” on page A-4 or Eclipse IDE help.
- 9 Plot the results that you get from the Eclipse environment. Compare the data from the Eclipse run with the data results from the test harness.
- 10 Close throttlecntrl\_testcode.

## **Test with Processor-in-the-Loop Testing**

For information, instructions, and examples, see “Processor-in-the-Loop (PIL) Simulation”.

## **Key Points**

- Methods for verifying code generated for an embedded system include running a Microsoft Windows run-time executable, SIL testing, PIL testing, and on-target rapid prototyping.
- You can reuse test data by importing and exporting test vectors.

## **Learn More**

- “Numerical Equivalence Testing”

## Evaluate Generated Code

| In this section...                                                      |
|-------------------------------------------------------------------------|
| “About this Tutorial” on page 3-62                                      |
| “Evaluate Code” on page 3-62                                            |
| “About the Compiler” on page 3-63                                       |
| “View Code Metrics” on page 3-63                                        |
| “About the Build Configurations” on page 3-63                           |
| “Configuration 1: Reusable Functions, Data Type Double” on page 3-64    |
| “Configuration 2: Reusable Functions, Data Type Single” on page 3-65    |
| “Configuration 3: Nonreusable Functions, Data Type Single” on page 3-66 |

### About this Tutorial

#### Learning Objectives

- Get familiar with the build characteristics of the code you generated for the throttle controller model
- Explore how different model configurations change the model’s RAM/ROM metric.

#### Prerequisites

#### Required Files

### Evaluate Code

Efficiency of generated code is based on two primary metrics: *execution speed* and *memory usage*. Often, faster execution requires more memory. Memory usage in ROM (read-only memory) and RAM (random access memory) presents compromises:

- Accessing data from RAM is faster than accessing data from ROM.



- Systems store executables and data using ROM because RAM does not maintain data between power cycles.

This section describes memory requirements divided into function and data components. Execution speed is not evaluated.

## About the Compiler

The Freescale™ CodeWarrior® is used in this evaluation.

| Compiler              | Version     | Target Processor |
|-----------------------|-------------|------------------|
| Freescale CodeWarrior | v5.5.1.1430 | Power PC 565     |

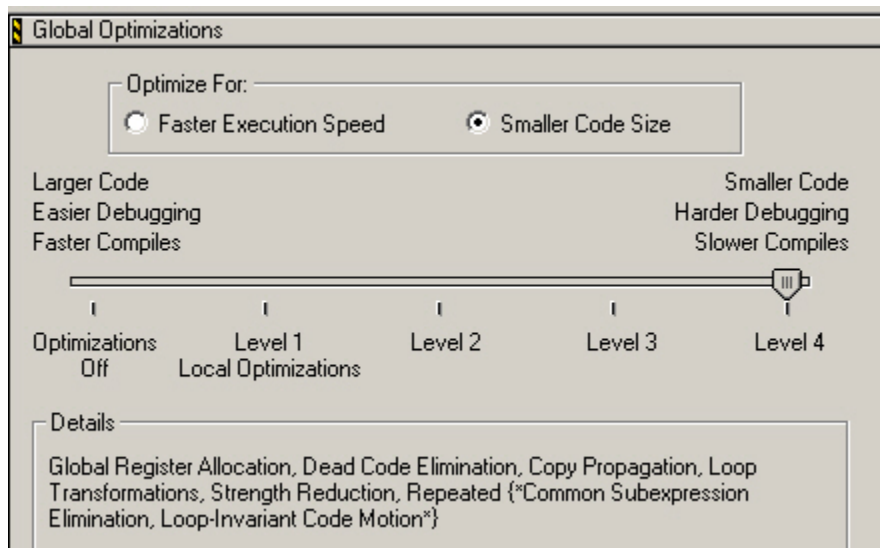
## View Code Metrics

As described in “Integrate Generated Code into External Environment” on page 3-43 and “Verify Generated Code” on page 3-52, the generated code might require utility functions. The utility functions have a fixed overhead. Their memory requirements are a one-time cost. Because of this, the data in this module shows the following memory usage.

|            |                                                                                   |
|------------|-----------------------------------------------------------------------------------|
| Algorithms | The C code generated from the Simulink diagrams and the data definition functions |
| Utilities  | Functions that are part of the Simulink Coder library source                      |
| Full       | The sum of both the Algorithm and Utilities                                       |

## About the Build Configurations

The same model configuration parameter settings are used in three evaluations. CodeWarrior is configured to minimize memory usage and apply all allowed optimizations.



## Configuration 1: Reusable Functions, Data Type Double

- **Source files:**  
`matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/CodeMetricFiles/PCG_Eval_CodeMetrics_1`
- **Data Type:** All doubles
- **Included Data:** All data required for the build is in the project (including data defined as extern: `pos_rqst`, `fbk_1`, and `fbk_2`)
- **Main Function:** A modified version of `example_main` from “Integrate Generated Code into External Environment” on page 3-43
- **Function-Call Method:** Reusable functions for the PI controllers

|                                   |     |     |   |
|-----------------------------------|-----|-----|---|
| defineImportedData.c              | 12  | 28  | • |
| defineImportedData.h              | 0   | 0   |   |
| eval_data.c                       | 0   | 288 | • |
| eval_data.h                       | 0   | 0   |   |
| example_main.c                    | 260 | 88  | • |
| PCG_Eval_Fil_Define_Throt_Param.c | 52  | 8   | • |
| PCG_Eval_Fil_Define_Throt_Param.h | 0   | 0   |   |
| PCG_Eval_File_1.c                 | 464 | 92  | • |
| PCG_Eval_File_1.h                 | 0   | 0   |   |
| PCG_Eval_File_1_private.h         | 0   | 0   |   |
| PCG_Eval_File_1_types.h           | 0   | 0   |   |
| PI_Cntrl_Reusable.c               | 384 | 44  | • |
| PI_Cntrl_Reusable.h               | 0   | 0   |   |
| rt_look1d.c                       | 220 | 20  | • |
| rt_look.c                         | 372 | 20  | • |

Utilities

Func | Data

### Memory Usage

| Usage Type | Function (bytes) | Data (bytes) |
|------------|------------------|--------------|
| Full       | 1764             | 589          |
| Algorithms | 1172             | 549          |
| Utilities  | 592              | 40           |

### Configuration 2: Reusable Functions, Data Type Single

In this configuration, the data types for the model are changed from the default of double to single.

- **Source files:**  
`matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/CodeMetricFiles/PCG_Eval_CodeMetrics_2`
- **Data Type:** All singles

- **Included Data:** All data required for the build is in the project (including data defined as extern: pos\_rqst, fbk\_1, and fbk\_2)
- **Main Function:** A modified version of example\_main from “Integrate Generated Code into External Environment” on page 3-43
- **Function-Call Method:** Reusable functions for the PI controllers

### Memory Usage

| Usage Type | Function (bytes) | Data (bytes) |
|------------|------------------|--------------|
| Full       | 1392             | 348          |
| Algorithms | 800              | 308          |
| Utilities  | 592              | 40           |

Comparing the memory used by the algorithms in the first configuration to the current configuration, there is a large drop in the data memory, from 549 bytes to 308 bytes, or 56 percent. The function size also decreased from 1172 to 800 bytes, or 68 percent. Running the simulation with data type set to single does not reduce the accuracy of the control algorithm. Therefore, this configuration is an acceptable design decision.

### Configuration 3: Nonreusable Functions, Data Type Single

- **Source files:**  
`matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/CodeMetricFiles/PCG_Eval_CodeMetrics_3`
- **Data Type:** All singles
- **Included Data:** All data required for the build is in the project (including data defined as extern: pos\_rqst, fbk\_1, and fbk\_2)
- **Main Function:** A modified version of example\_main from “Integrate Generated Code into External Environment” on page 3-43
- **Function-Call Method:** The function interface is `void void`. Global parameters pass the data.

The memory requirements for the third configuration are higher than the memory requirements for the second configuration. If the data type is doubled, the memory requirements are higher than the first configuration, as well.

### Memory Usage

| Usage Type | Function (bytes) | Data (bytes) |
|------------|------------------|--------------|
| Full       | 1540             | 388          |
| Algorithms | 948              | 348          |
| Utilities  | 592              | 40           |



# Installing and Using IDE

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- “Installing Eclipse IDE and Cygwin Debugger” on page A-2
- “Integrating and Testing Code with Eclipse IDE” on page A-4

## Installing Eclipse IDE and Cygwin Debugger

| In this section...                           |
|----------------------------------------------|
| “Installing the Eclipse IDE” on page A-2     |
| “Installing the Cygwin Debugger” on page A-3 |

### Installing the Eclipse IDE

This section describes how to install the Eclipse IDE for C/C++ Developers and the Cygwin debugger for use with the integration and verification tutorials. Installing and using the Eclipse IDE for C/C++ Developers and the Cygwin debugger is optional. Alternatively, you can use another Integrated Development Environment (IDE) or use equivalent tools such as command-line compilers and makefiles.

- 1 From the Eclipse Downloads web page (<http://www.eclipse.org/downloads/>), download the Eclipse IDE for C/C++ Developers to your C: drive.

You also need the Eclipse C/C++ Development Tools (CDT) that are compatible with the Eclipse IDE. You can install the CDT as part of the Eclipse C/C++ IDE packaged zip file or you can install it into an existing version of the Eclipse IDE.


| If You Install the CDT...                          | Then...      |
|----------------------------------------------------|--------------|
| As part of the Eclipse C/C++ IDE packaged zip file | Go to step 4 |
| Into an existing version of the Eclipse IDE        | Go to step 2 |

- 2 From the Eclipse CDT Downloads page (<http://www.eclipse.org/cdt/downloads.php>), download the Eclipse C/C++ Development Tools (CDT) that is compatible with your installed version of the Eclipse IDE.
- 3 Unzip the downloaded Eclipse CDT zip file. Copy the contents of the directories `features` and `plugins` to the corresponding directories in `c:\eclipse`.



- 4 Create the folder `c:\eclipse`.
- 5 Unzip the downloaded Eclipse IDE zip file into `c:\eclipse`.
- 6 On your desktop, create a link to the executable file `c:\eclipse\eclipse.exe`.

## Installing the Cygwin Debugger

- 1 From the Cygwin home page (<http://www.cygwin.com>), download the `setup.exe` file.
- 2 Run the `setup.exe` file. A Cygwin Setup - Choose Installation Type dialog box opens.
- 3 Follow the installation procedure:
  - Select the option for installing over the Internet.
  - Accept the default root folder `c:\cygwin`.
  - Specify a local package folder. For example, specify `c:\cygwin\packages`.
  - Specify how you want to connect to the Internet.
  - Choose a download site.
- 4 In the dialog box for selecting packages, set the **Devel** category to **Install** by clicking the selector icon .
- 5 Add the folder `c:\cygwin\bin` to your system Path variable. For example, on a Windows XP system:
  - a Click **Start > Settings > Control Panel > System > Advanced > Environment Variables**.
  - b Under **System variables**, select the Path variable and click **Edit**.
  - c Add `c:\cygwin\bin` to the variable value and click **OK**.

---

**Note** To use Cygwin, your build folder must be on your C drive. The folder path cannot include any spaces.

---

## Integrating and Testing Code with Eclipse IDE

### In this section...

“About Eclipse” on page A-4

“Define a New C Project” on page A-5

“Configure the Debugger” on page A-6

“Start the Debugger” on page A-6

“Set the Cygwin Path” on page A-7

“Debugger Actions and Commands” on page A-7

### About Eclipse

Eclipse ([www.eclipse.org](http://www.eclipse.org)) is an integrated development environment for developing and debugging embedded software. Cygwin ([www.cygwin.com](http://www.cygwin.com)) is an environment that is similar to the Linux environment, but runs on Windows and includes the GCC compiler and debugger.

This section contains instructions for using the Eclipse IDE with Cygwin tools to build, run, test, and debug projects that include generated code, as described in “Integrate Generated Code into External Environment” on page 3-43 and “Verify Generated Code” on page 3-52. There are many other software packages and tools that can work with code generation software to perform similar tasks.

“Installing Eclipse IDE and Cygwin Debugger” on page A-2 contains instructions for installing Eclipse and Cygwin. Before proceeding, be sure you have installed Eclipse and Cygwin, as described in that section.

To use Cygwin, your build folder must be on your C drive. The folder path cannot include any spaces.

### Project and File Names

“Integrate Generated Code into External Environment” on page 3-43 and “Verify Generated Code” on page 3-52 both use the instructions in this section, but the project names and file names differ. Where you see ## in a project name or file name, substitute:

- `externenv`, if you are working in “Integrate Generated Code into External Environment” on page 3-43
- `testcode`, if you are working in “Verify Generated Code” on page 3-52

## Define a New C Project

- 1** In Eclipse, choose **File > New > C Project**. A C Project dialog box opens.
- 2** In the C Project dialog box:
  - a** In the **Project name** field, type the project name `throttlecntrl_##` (`##` is `externenv` or `testcode`).
  - b** In the **Location** field, specify the location of your build folder (for example, `C:\EclipseProjects\throttlecntrl\externenv`).
  - c** In the **Project type** selection box, select and expand **Makefile project**.
  - d** Click the **Empty Project** node.
  - e** Under **Other Toolchains**, select **Cygwin GCC**.
  - f** Click **Next**. A Select Configurations dialog box opens.
- 3** In the Select Configurations dialog box, click **Advanced settings**. The Properties dialog box appears.
- 4** In the Properties dialog box:
  - a** Select **C/C++ Build**.
  - b** Select **Generate Makefiles automatically**.
  - c** Select the **Behavior** tab.
  - d** Select **Build on resource save (Auto build)**.
  - e** Click **Apply** and **OK**.The Properties box closes.
- 5** In the Select Configurations dialog box, click **Finish**.

## Configure the Debugger

- 1 In Eclipse, choose **Run > Debug Configurations**. The Debug Configurations dialog box opens.
- 2 Double-click **C/C++ Application**. A **throttlecntrl\_externenv Default** entry appears under **C/C++ Application**. The **Main** tab of the configuration pane appears on the right side of the dialog box with the following parameter settings:

| Parameter              | Setting                             |
|------------------------|-------------------------------------|
| Name                   | throttlecntrl_externenv Default     |
| C/C++ Application      | Default\throttlecntrl_externenv.exe |
| Project                | throttlecntrl_externenv             |
| Build configuration    | Default                             |
| Enable auto build      | Cleared                             |
| Disable auto build     | Cleared                             |
| Use workspace settings | Selected                            |

- 3 Click **Close**.

## Start the Debugger

To start the debugger:

- 1 In the main Eclipse window, select **Run > Debug**. A Confirm Perspective Switch dialog box opens.
- 2 Click **Yes**. Tabbed debugger panes that display debugging information and controls are displayed in the main Eclipse window.
- 3 Specify the location of the project files. The Cygwin debugger creates a virtual drive (for example, `main()` at `/cygdrive/`) during the build process. To run the debugger, Eclipse remaps the drive or locates your project files. Once Eclipse locates the first file, it automatically finds the remaining files. In the Eclipse window, click **Locate File**. The Open dialog box opens.

For information on using the **Edit Source Lookup Path** button, see “Set the Cygwin Path” on page A-7.

- 4 Navigate to the `example_main.c` file and click **Open**. Your program opens in the debugger software.

## Set the Cygwin Path

The first time you run Eclipse, you get an error related to the Cygwin path.

To provide the path information:

- 1 Open the Debug Configurations dialog box by selecting **Run > Debug Configurations > C/C++ Application**.
- 2 Click the **Source** tab.
- 3 Click **Add**. The Add Source dialog box opens.
- 4 Select **Path Mapping** and click **OK**. The Path Mappings dialog box opens.
- 5 Click **Add**. In the **Compilation path** field, type `\cygdrive\c\`.
- 6 In the **Local file system path** field, click the **Browse** button, navigate to your `C:\` drive, and click **OK**.
- 7 Click **Apply**.
- 8 Click **Close**.

## Debugger Actions and Commands

The following actions and commands are available in the debugger.

| Action             | Command          |
|--------------------|------------------|
| Step into          | F5               |
| Step over          | F6               |
| Step out           | F7               |
| Resume             | F8               |
| Toggle break point | Ctrl + Shift + B |